VOLUME XXXIX NUMBER 3

THE
JOURNAL OF GEOLOGY

April-May 1931

REVISION OF THE PAYETTE AND IDAHO FORMATIONS[1]

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ABSTRACT

The history of the Payette and Idaho formations and their place in the literature is reviewed. Previous to 1928 the formations were mapped as a unit and undifferentiated. Evidence is presented which shows that the true Payette formation is exposed only on the flanks of the downwarp which comprises the great Snake River plains. Its characteristic occurrence is between two great lava extrusions. It has a characteristic lithology and a flora of Miocene age. The Idaho formation occupies the surface over much of the plains area and was formerly referred to as Payette and Idaho formations. It possesses a great thickness and overlies the Columbia River basalt and the Owyhee rhyolite. It has a characteristic lithology and a fauna and flora of Pliocene and later age. By the revision, new age relations, stratigraphic positions, and areal distribution are established but no confusion results because at the same time the originally assigned names and ages, which are now established in the literature, may be retained.

INTRODUCTION

The data and conclusions presented in the following pages are results of field work undertaken for the Idaho Bureau of Mines and Geology in executing economic investigations. The writer spent eight weeks of field work on parts of the area in 1920 and the main regional stratigraphic and structural implications were gained at that time. These were amply confirmed by subsequent more detailed work which constituted a week's work in November, 1921, a week's work in 1926, and four weeks in 1927. Finally, the earlier results were enriched and amplified by twelve weeks of detailed work on the

[1] This work was done in co-operation with the Idaho Bureau of Mines and Geology, and the results are published with the permission of the secretary.

map area in 1928. The bulk of the material presented herein has thus been under consideration by the writer for ten years.

ACKNOWLEDGMENTS

The writer acknowledges with appreciation aid from the Idaho Bureau of Mines and Geology which financed the field work for this paper, help from the United States Geological Survey in the determination of fossils, and many suggestions from various members of the Department of Geology, University of Chicago. Courtesies also were extended the writer by various secretaries of the Idaho Bureau of Mines and Geology. Able assistance was given in the field by Messrs. M. Melville Johnson, H. L. McKinley, and Clarence F. Myrene.

HISTORY OF THE PAYETTE AND IDAHO FORMATIONS

In 1870 Meek[1] gave a list of invertebrate fossils collected from Tertiary sediments on Castle Creek, Idaho. These he correlated with other fossils collected from Fossil Hill, Nevada. *Sphaerium* (?) *idahoense* was determined from both localities and was the basis for correlation. On this basis King,[2] in 1878, when assigning the Truckee group to the Fossil Hill, Nevada, beds also applied that name to the beds on Castle Creek, Idaho. White[3] noted, in 1882, that King assigned the Castle Creek group of beds to the Truckee group. He also assigned a Miocene age to the beds.

In 1883 Cope[4] described fish remains from sediments at a Castle Creek locality and called them the "Idaho group." He assigned to them a Lower and Middle Pliocene age. He also placed Meek's mollusks from Castle Creek and Fossil Hill in this group with a Pliocene age. King, in 1878, referred the Truckee group to the Miocene, but he referred the Idaho beds to the Pliocene.[5]

In 1898 Lindgren[6] gave the name Payette formation to a large area of lake deposits in this region. These he referred to the Miocene

[1] F. B. Meek, *Acad. Nat. Sci. Phila. Proc. for 1870*, pp. 56–57.

[2] Clarence King, *U.S. Geol. Expl., Fortieth Par. Rept.*, Vol. I (1878), pp. 412, 440.

[3] C. A. White, "The Idaho Formation," *U.S .Nat. Mus. Proc.*, Vol. V (1882), p. 100, Pl. 5, Figs. 17–20.

[4] E. D. Cope, *Acad. Nat. Sci. Phila. Proc. for 1883*, pp. 153–66.

[5] *Op. cit.*, p. 440.

[6] Waldemar Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part III (1898), pp. 625–736.

on the floral evidence determined by Knowlton.[1] Lindgren said, in naming this formation, that,

> This formation is probably not the same as Cope's Idaho formation, to which a Pliocene age was assigned.

In a footnote on this page he said:

> From the results of more extended surveys during the summer of 1897 it has become evident that the Payette and Idaho formations represent two successive stages of the lake, the often deformed shore line of the former being found at elevations of from 4,200 to 5,000 feet, and those of the latter at a maximum elevation of 3,000 feet. To separate the deposits of the two formations is not always easy.

In 1902 Knowlton[2] changed his interpretation of the age of the Payette formation from Upper Miocene to Upper Eocene. He said:

> In this report the Payette formation was referred to the Upper Miocene, but I was misled by the knowledge then current regarding the position of the Bridge Creek beds, as I have already pointed out, and it is now necessary to change that reference. The flora of the Payette formation undoubtedly finds its greatest affinity with that at Bridge Creek, a fact recognized all along, and, like it, is now referred to the Upper Eocene.

Lindgren,[3] in 1904, first recognized areal outcrops of the Idaho formation. He said:

> In the vicinity of Nampa the later lake beds and basalt filled the valley to elevations of 2,700 to 2,800 feet, and the sediments contain numerous bones of mammals and of fishes. . . . . The age of the scant fauna has been determined as Pliocene by Professor Lucas, and the name Idaho formation has been given to these beds. . . . . For practical purposes the Tertiary lake beds form one continuous series, for it is not always possible to separate with certainty the deposits of the Payette formation from those of the Idaho.

Russell[4] and Washburne,[5] in his 1909 paper, accepted Lindgren's division of the lake beds and agreed with him that the two are

[1] F. H. Knowlton, "Fossil Plants of the Payette Formation," *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part III (1898), pp. 721–44, Pls. XCIX–CII.

[2] F. H. Knowlton, "Flora of the John Day Basin," *U.S. Geol. Surv. Bull. 204*, p. 110.

[3] Waldemar Lindgren and N. F. Drake, "Descriptions of the Nampa Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio 103* (1904).

[4] I. C. Russell, "A Geological Reconnaissance in Southern Oregon," *U.S. Geol. Surv. Fourth Ann. Report* (1884), pp. 431–64; "Geology and Water Resources of the Snake River Plains of Idaho," *U.S. Geol. Surv. Bull. 199* (1902); "Preliminary Report on Artesian Basins in Southwestern Idaho and Southeastern Oregon," *U.S. Geol. Surv., Water-supply Paper 78* (1903).

[5] C. W. Washburne, "Gas and Oil Prospects near Vale, Oregon, and Payette, Idaho," *U.S. Geol. Surv. Bull. 431* (1909), pp. 26–35.

practically indistinguishable in the field. In 1912 Blackwelder[1] wrote, "The Payette formation, which seems to be safely identified by fossil plants as of late Eocene age."

In 1913, Umpleby[2] said that Knowlton had determined fossil leaves from beds in Lemhi County, as Miocene. Umpleby correlated these with the Payette formation and believed these beds to be an extension of the Payette which, by inference, he believed to be Miocene.

In 1913, Umpleby[3] pointed out that Lindgren and Russell believed that the Hailey and Salmon City lake beds are Payette in age, and inferred later in his text that the Payette may also be Miocene, and that an Eocene age may be incorrect.

In 1917, Merriam[4] said:

> The Idaho formation is not as yet satisfactorily separated from the Payette, Eocene or Miocene and from a Miocene or Pliocene stage which may intervene between the Payette and Idaho. It is, however, quite certain that there exists over a large area of Southwestern Idaho a formation several hundred feet thick which may show evidence of deformation and which contains a fauna of a stage representing either the latest Pliocene or the earliest Pleistocene.

Buwalda,[5] in his paper published July, 1921, reviewed the history of the two formations briefly, and said:

> The investigations of the writer appear to indicate that at least the larger part of the areas regarded as Eocene age are in reality Miocene, or possibly Lower Pliocene, and that the Idaho formation, if Pliocene, was deposited very late in that epoch and may be Pleistocene in age. It is probable, moreover, that the Tertiary strata are divisible into more than two formations. Collections of mammalian fossils made by the writer in Idaho very near the Oregon boundary suggest that the Payette formation is itself divisible into at least two formations of somewhat different age.

[1] Eliot Blackwelder, "The Old Erosion Surface in Idaho," *Jour. Geol.*, Vol. XX (1912), pp. 410–14.

[2] Joseph B. Umpleby, "Geology and Ore Deposits of Lemhi County, Idaho," *U.S. Geol. Surv. Bull. 528* (1913).

[3] Joseph Umpleby, "The Old Erosion Surface in Idaho," *Jour. Geol.*, Vol. XXI (1913), pp. 224–31.

[4] John C. Merriam, *Calif. Univ. Dept. Geol. Bull.*, Vol. X (1917), p. 432.

[5] J. P. Buwalda, "Oil and Gas Possibilities of Eastern Oregon," *Ore. Bur. of Mines and Geol.*, Vol. III, No. 2 (1921).

Chaney,[1] in 1922, discussing the Payette formation, said, "At this time the writer is satisfied to make the reference to the Miocene without further specifications."

In 1923, Buwalda[2] assigned a Middle or Lower Miocene age to the Payette under the rhyolite, but also said:

> The Poison Creek formation immediately overlying the rhyolite is made up of ash, clays, shales and sandstones very similar to the Payette but contains mammalian fossils indicating an age Lower Pliocene or later.

On the same page he said:

> The Idaho formation lies in the middle and flatter part of the valley unconformably on the underlying formations. It is generally made up of cream-tinted silt and volcanic ash. Mammalian remains indicate a Pleistocene age.

Gilbert,[3] in 1890, also argued for Pleistocene age for the Equus beds and the Equus fauna.

Buwalda,[4] in July, 1924, said:

> In the course of field studies in the Snake River region the writer secured remains of two mammalian faunas from the Payette. One occurs in the lower part of the formation, in beds beneath the interbedded rhyolite, about one mile north of Rockville, shown on the Silver City quadrangle of the U.S. Geological Survey. The second was found in the same section in strata overlying the rhyolite, probably disconformably, near Sands, about 11 miles northeast of Rockville. The beds at both localities dip to the north beneath the nearly horizontal Idaho formation, from which they are easily discriminated by their attitude and lithology.

In speaking of the lower fauna on the same page, he said, "This fauna may represent the middle Miocene, but it is more probably of upper Miocene age, and possibly even lower Pliocene."

In speaking of the Sands fauna, he said, "The age of the fauna is approximately lower Pliocene."

He also said,[5] "The Payette overlies, probably conformably, the

[1] Ralph Chaney, "Notes on the Flora of the Payette Formation," *Amer. Jour. Sci.*, 5th Series, Vol. IV (1922), pp. 214–22.

[2] J. P. Buwalda, "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho," *Ida. Bur. of Mines and Geol., Pamph. 5* (1923).

[3] G. K. Gilbert, "Lake Bonneville," *U.S. Geol. Surv. Mono. I* (1890), pp. 393–402.

[4] J. P. Buwalda, "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *Sci.*, Vol. LX, No. 564, pp. 572–73.

[5] *Op. cit.*, p. 573.

Columbia River lavas, which in other localities have been determined to be approximately Middle Miocene in age."

In December, 1924,[1] the writer quoted Buwalda's[2] paper of July, 1923, for the ages of the formations. The writer, at this time, was inclined to substitute the name Poison Creek for the Idaho formation and to consider only one formation to overlie the rhyolite.

In June, 1928,[3] the writer said:

> The geological column of the Weiser quadrangle of Middle Miocene age has, so far as observed, the Columbia River basalt at its base. This is succeeded by about 600 feet of continental and lake-bed sediments which are tentatively called the Payette formation. Above these sediments lies about 600 feet of lava, also assigned to Columbia River basalt.
>
> Immediately overlying the upper basalt occurs the massive grit or sandstone locally known as the Boise sandstone. This formation, along with a varying thickness of sandy and shaly layers, is assigned to the Poison Creek formation of probable Pliocene age. Above this, and with a slight angular unconformity, lies several hundred feet of almost unconsolidated but distinctly stratified sands and clays, which are tentatively called the Emmett formation and which have their origin in deltas, fans and alluvial flood plains of Pleistocene age.

It can be seen that the Payette was here referred to the series underlying the Columbia River basalt and that the tendency was again to substitute Poison Creek for Idaho as a name for the series overlying the basalt. The name Emmett was first proposed here as a term to include part of what was originally called Idaho. A Middle Miocene age is here assigned to the true Payette and a Pliocene age for the sediments overlying the Columbia River basalt.

In 1929, Bryan,[4] in writing of the Payette and Idaho formations, accepted Lindgren's original definitions of them, but said, "It is difficult to distinguish between these formations, and the deposits mapped and described in this report as Payette formation may in places include beds belonging to the Idaho formation."

[1] Virgil R. D. Kirkham, "Oil Possibilities and Drilling Activities in South Idaho," *Ida. Eng.*, Vol. II, No. 1 (December, 1924).

[2] "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *op. cit.*

[3] Virgil R. D. Kirkham, "A Brief Preliminary Report on the Possibilities of an Underground Water Supply for the City of Weiser, Idaho," *Ida. Bur. of Mines and Geol. Pamph. 29* (June, 1928), p. 1.

[4] Kirk Bryan, "Geology of Reservoir and Dam Sites with a Report on the Owyhee Irrigation Project, Oregon," *U.S. Geol. Surv., Water-supply Paper 597A* (January, 1929).

In summary, the lake beds were called Truckee group by King in 1878; Idaho group by Cope in 1883; Payette and Idaho formations by Lindgren in 1898; Payette, Poison Creek, and Idaho formations by Buwalda in 1923; Payette and Poison Creek formations by Kirkham in 1924; and Payette, Poison Creek, and Emmett formations by him in 1928. The Payette beds have been assigned by various writers to each of the Tertiary periods. The Idaho beds have been assigned to the Miocene, Pliocene, and Pleistocene. Up to the time of this paper all writers, except Bryan, avoided differentiation of the Payette and Idaho, and showed no boundaries on areal maps. Bryan, on his Plate III, showed about a quarter of a square mile of Idaho formation without boundaries. Lindgren[1] in his text vaguely referred the Idaho formation to the region "in the vicinity of Nampa" and to elevations below 2,800 feet.

Lindgren[2] suggested that the lower part of the Payette was interbedded with the early Neocene basalt. On the same page he said, "North of Marsh the beds are sandy, with subordinate layers of brown clayey tuff. They appear to dip below the Squaw Butte basalt flow on the west and to be underlain by basalt flow on the east."

Lindgren and every other worker up to Buwalda considered the lake beds and terrestrial material overlying the basalt on the north side of the plains, and overlying the rhyolite on the south side, to be chiefly Payette formation covered in places with minor amounts of Idaho formation. Buwalda[3] recognized that the Payette is interbedded with the Columbia lavas, and said "Rhyolite flows of 1,000 feet in thickness overlie the Payette for a great distance on the south side of the valley."

This statement apparently consigns the Payette to a position below the rhyolite. In the next paragraph he said, "The Poison Creek formation immediately overlying the rhyolite is made up of ash, clays, shales, and sandstones very similar to the Payette but contains mammalian fossils indicating an age of lower Pliocene or later."

[1] Lindgren, *op. cit.*

[2] Waldemar Lindgren, "Description of the Boise Quadrangle," *U.S. Geol. Surv. Geol. Atlas Folio 45* (1898).

[3] Buwalda, "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho," *op. cit.*, p. 2.

This statement indicates clearly that Buwalda believed the sediments below the rhyolite to be Payette but that the sediments above the rhyolite were not Payette. This is also indicated by the new name of Poison Creek formation assigned to this group. This was the first time that sediments above the rhyolite were excluded from the Payette.

Buwalda,[1] in 1924, apparently reconsidered and decided that the Poison Creek is the top part of the Payette. In speaking of two faunas from the Payette, he said, "One occurs in the lower part of the formation, in beds beneath the interbedded rhyolite. . . . . The second was found in the same section in strata overlying the rhyolite, probably disconformably."

Although he assigned a greatly different age value to the two faunas, he was apparently willing to consider them both Payette. On page 573, he said, "The Payette overlies, probably conformably, the Columbia River lavas."

The writer,[2] in his 1924 paper, accepted Buwalda's 1923 conclusion and confined the Payette to the sediments below the rhyolite and gave Buwalda's name Poison Creek formation to all of the sediments above the rhyolite and to those above the Columbia River basalt on the north. The writer,[3] in 1928, reiterated this idea specifically for the Weiser area where it is plainly stated that the Payette represented lake beds underlying 600 feet of Columbia River basalt. At this time, however, the beds above the basalt were not all classed as Poison Creek, and the Emmett formation was suggested for a limited area near Emmett that was not characteristic of the Poison Creek formation.

The idea of unconformability, probably engendered by the conception of age differences, seems to have been held generally by all writers.

Buwalda considered the Idaho formation to be unconformable with Poison Creek. The writer accompanied him on this field work and although he failed to see actual angular unconformable contacts,

[1] "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *op. cit.*

[2] Kirkham, "Oil Possibilities and Drilling Activities in South Idaho," *op. cit.*

[3] Kirkham, "A Brief Preliminary Report on the Possibilities of an Underground Water Supply for the City of Weiser, Idaho," *op. cit.*

he accepted the idea of angular unconformity of the so-called Idaho formation with the Poison Creek formation and carried it up to 1927. The 1928 field season convinced the writer that evidence is lacking for an angular unconformity in lake beds above the Columbia River basalt and rhyolite.

The writer is now prepared to present evidence to support the following ideas. (1) A series of terrestrial deposits and lake beds exists in the Columbia River basalt 600 or more feet below its upper surface. This series presents a characteristic lithology and a flora of Miocene age. (2) A series of terrestrial deposits and lake beds, in places several thousand feet thick, overlies the Columbia River basalt and the Owyhee rhyolite and presents a characteristic lithology and a flora and fauna of Pliocene and later age. According to the original definitions of the Payette formation none of the upper series may be included in it, but the series underlying the basalt and rhyolite can be shown to be true Payette. According to the original definition of the Idaho formation, all of the upper series should be included in it.

If this age relation, stratigraphic position, and areal distribution can be established by this paper, confusion can be dispelled and at the same time the originally assigned names and ages, which are now well established in the literature, may be retained.

PHYSICAL EVIDENCE

For convenience throughout the rest of this discussion, the Tertiary sediments will be defined as follows: *basin beds* will refer to all lake beds and terrestrial sediments overlying the upper flow of the Columbia River basalt or the rhyolite. *Intermontane beds* will refer to all lake beds and terrestrial sediments underlying several hundred feet of Columbia River basalt or rhyolite. These, in no case, occur in the plains area.

STRUCTURAL RELATIONS

The basin beds overlie the Columbia River lava on the north edge of the plains without marked angular unconformity (see Fig. 1, A_5–A_6) but with considerable disconformity caused by erosion of the upper basalt flows before deposition of the basin beds. They also overlie the rhyolite on the south border of the plains without marked

angular unconformity, but with a similar disconformity. The basin beds lie in a structural depression of great size called in this paper the Snake River downwarp and their distribution is confined to the downwarp area (see Figs. 1 *B*, 13). These beds strike generally in a

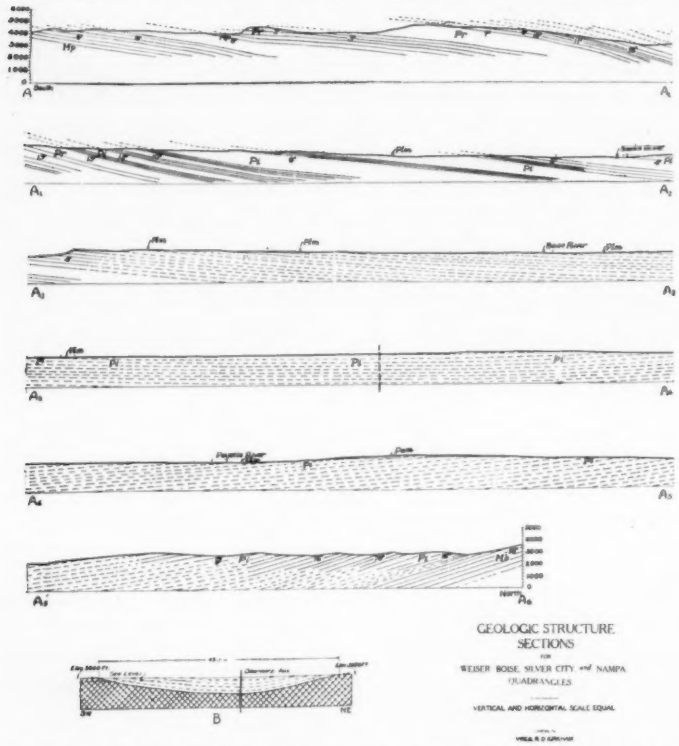


FIG. 1.—*Mp* is the Payette formation, *Pr* is the rhyolite series, *Pi* is the Idaho formation, *Plm* is the Lower Mesa formation, and *Pum* is the Upper Mesa formation. *Mb* is Columbia River basalt.

direction approximately parallel to the downwarp axis and dip at varying degrees toward the center of the depression and approximately at right angles to the downwarp axis. The lower beds cropping out close to the lava at the edges of the downwarp, dip more steeply than those slightly farther out in the valley (see Figs. 2 and

3). Thus a traverse at right angles to the strike of the downwarp takes the observer over the truncated edges of beds dipping pro-

FIG. 2.—Looking southeast along the strike of the Idaho lake beds which dip southwest to the downwarp axis near Alkali Creek on the north side of the downwarp.

FIG. 3.—Idaho lake beds dipping gently to the downwarp axis from the south side. These are characteristic of the upper members.

gressively less as he approaches the axis of the depression. For example, a member near the rhyolite on the south side of the down-

warp actually dips northeast at an angle of 12.° In less than a mile in the direction of dip the angle has insensibly lessened to 11°, and in a distance of another mile the angle of dip has decreased to 10°

FIG. 4.—Idaho beds in the Weiser quadrangle dipping southwest to the axis of the downwarp.

FIG. 5.—Idaho beds in the Nampa quadrangle overlying the rhyolite and dipping toward the downwarp axis to the northeast. Note the irregular surface of the rhyolite projecting through the lake beds.

or less. The highest dips measured in the basin beds on the south side of the downwarp were 16° in a member immediately overlying the rhyolite (Fig. 5 and Fig. 7). About 9 miles closer to the axis of the downwarp the dip has decreased to 4° (Fig. 3). Still nearer the

axis of the downwarp the dips grow less until they approach horizontally 20 miles from the first point. The same phenomenon is observed on the north side of the downwarp axis, except that along the north side the dips are steeper (Fig. 2 and Fig. 4). The beds immediately overlying the basalt dip at angles as high as 29° in places. Eight miles nearer the axis the dip has decreased to 16° or less. At other places on the north side where the dip is 18° at the border it decreases to 7° within 3 miles. In each case there is a progressive range of dips between the two extremes, with a change so insensible that angular unconformities are undetectable. The phenomena, as a whole, are explained by continuous deposition in a progressively sinking area. The beds which were deposited first have been tilted most, and those deposited last have been tilted least, with all gradations existing in between. If one starts at the edge of the downwarp and walks a mile toward the center of the basin he will be standing on sediments several hundred feet stratigraphical-

FIG. 6.—Looking east, beds of the Idaho formation dipping northeast on the south side of the downwarp

ly higher than those from where he started. These obviously are also later in age, and in the course of several miles one passes over several thousand feet of sediments representing a great time interval. Obviously fossils collected from the last deposited beds probably would not be identical with those deposited at the bottom of the series or at horizons in between.

A study of the literature shows that before the reconnaissance by Buwalda and the writer in 1920, this inward dipping relationship was not commonly recognized. The basin beds were universally assumed to be nearly horizontal with the Idaho formation lying in the

FIG. 7.—Looking north at Payette lake beds, on the left, dipping east under Columbia River basalt on the right, near Cobb Siding.

center of the basin and thinly masking the Payette except where erosion had cut through it into the supposed underlying Payette formation. Lindgren,[1] in speaking of the basin beds, which he calls the Payette, said, "Over the larger part of its extent the formation lies nearly horizontal or dips only a few degrees."

In his Boise folio[2] he duplicates the statement and says, also:

> During the time of the maximum extension of the Payette Lake, its surface stood at the present elevation of 4,100 feet. Its deposits, over 1,000 feet thick near the shore, rested against the abrupt slope of Boise Ridge and filled the old canyon of the Boise to the same depth.

It is obvious from this statement that Lindgren believed the beds to have been deposited nearly horizontally and that there had been little or no movement in the region since their deposition. He ap-

[1] *Op. cit.*, p. 632. [2] *Op. cit.*, p. 2.

parently thought that the highest remnants of lake beds recorded the highest elevation reached by the lake.

Under the writer's conception the first basin beds were deposited on an approximately level surface of lava which has since been warped[1] so that one of the early level horizons may have later extended from several thousand feet below sea level to several thousand feet above sea level. Persuasive evidence exists for believing that the region now called Boise Ridge was at one time entirely covered by Columbia River basalt and the basin beds, and then uplifted after which most of the lava and basin beds were removed, leaving the present exhumed surface of Boise Ridge dipping at an angle nearly identical with the lake bed and lava remnants at its base.

So far as is shown by the literature all workers but Buwalda and the writer have followed Lindgren in assuming the basin beds to be nearly horizontal. With this idea in mind fossils collected from two nearby localities have been assumed by many workers to represent practically the same horizon. But, as a matter of fact, collections made within a mile of each other if not on the strike of a well-marked member might represent fauna or flora from horizons stratigraphically several hundred feet apart. Thus it can be readily understood how workers, not recognizing the above possibility, have assigned to these basin beds ages ranging from Eocene to Pleistocene.

The intermontane beds on the Boise quadrangle dip at higher angles toward the axis of the downwarp than do the basin beds. This was noted by Lindgren;[2] he said, "The smaller detached masses in the intermontane valley are still more disturbed, generally dipping at angles up to 50°."

In describing the intermontane beds north of Montour, he said, "The dip is from 3° to 10° W." The writer found a 19° dip to the west in this area. The intermontane beds shown on the map area in the Boise quadrangle are conformable with the overlying Columbia River basalt and dip in a monocline which is the northeast flank of the Snake River downwarp.

The best exposures of the intermontane beds are on the Weiser

[1] Virgil R. D. Kirkham, "Old Erosion Surfaces in Southwestern Idaho," *Jour. Geol.*, Vol. XXXVII (1930), pp. 653–58.

[2] *Op. cit.*, p. 2.

River. These are confined to Paddock and Linson valleys, and to the valleys of Crane Creek and Weiser River. Here the intermontane beds are exposed only where anticlines in the Columbia

FIG. 8.—Payette beds dipping under the Owyhee rhyolite cap toward the downwarp. The small patch of rhyolite on the right has slumped from the main mass.

FIG. 9.—Payette beds under the upper series of Columbia River basalt in Linson Valley.

River basalt have been eroded through the upper series of flows (see Figs. 9 and 11). On Weiser River erosion has cut through the intermontane beds and into the underlying series of Columbia River lavas (see Figs. 12 *BB*, 13). A similar exposure occurs on an eroded

anticline at Cobb Junction about 13 miles west of Weiser (see Figs. 7, 12 *HH*, 13). Dips on the limbs of this anticline were measured up to 8°. On Weiser River the beds dip as high as 16° on the southwest flank of the fold, and 10° on the northeast flank. Similar dips were measured on the other folds in Weiser quadrangle. In all cases the beds were conformable with the overlying Columbia River basalt and dipped at similar angles.

FIG. 10.—Looking north along the strike of the Idaho beds overlying Columbia River basalt at Black Canyon dam.

In the southern limb of the downwarp the intermontane beds underlie the rhyolite and are exposed in the southwestern part of the map area in Silver City quadrangle. The dip here is flattest farther south and steepens to the northeast, reaching 15° in places. The overlying rhyolite (see Figs. 9, 12 *GG*, 14, 15) has similar dips which steepen notably to the northeast. Thus both the rhyolite and intermontane beds on the southwest limb of the downwarp dip toward the axis.

STRATIGRAPHIC POSITION

That the basin beds overlie the Columbia River basalt and the rhyolite has been generally conceded by all writers. Lindgren showed this relation in several papers. He believed the contact to be disconformable, and said, "On the west the basalts border against

the Payette sandstones and, as far as can be seen, dip below them, forming a very uneven surface, upon which the Payette sandstones were deposited."

He did not say, at any place, anything concerning angular unconformity. Buwalda,[1] in describing the basin beds, said, "The second was found in the same section in strata overlying the rhyolite, probably disconformably."

FIG. 11.—Looking south along the strike at basalt beds dipping east from the axis of the anticline in Linson Valley. The patch in the valley is Payette lake beds underlying the basalt.

But on another page he said, "The Payette overlies, probably conformably, the Columbia River lavas."

Stratigraphically the basin beds and the intermontane beds are at all places separated by great thicknesses of lava. On the south side of the plains in the Silver City quadrangle, the basin beds are separated from the intermontane beds by at least 1,850 feet of rhyolite. In the Boise quadrangle only 200 feet of rhyolite separate the two series. At this place, however, the rhyolite exists only as an erosional fragment and undoubtedly at one time possessed a greater thickness.

At Squaw Butte there are 251 flows of Columbia River basalt, dipping at angles ranging from 8° to 40°, between the two series.

[1] "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *op. cit.*, p. 572.

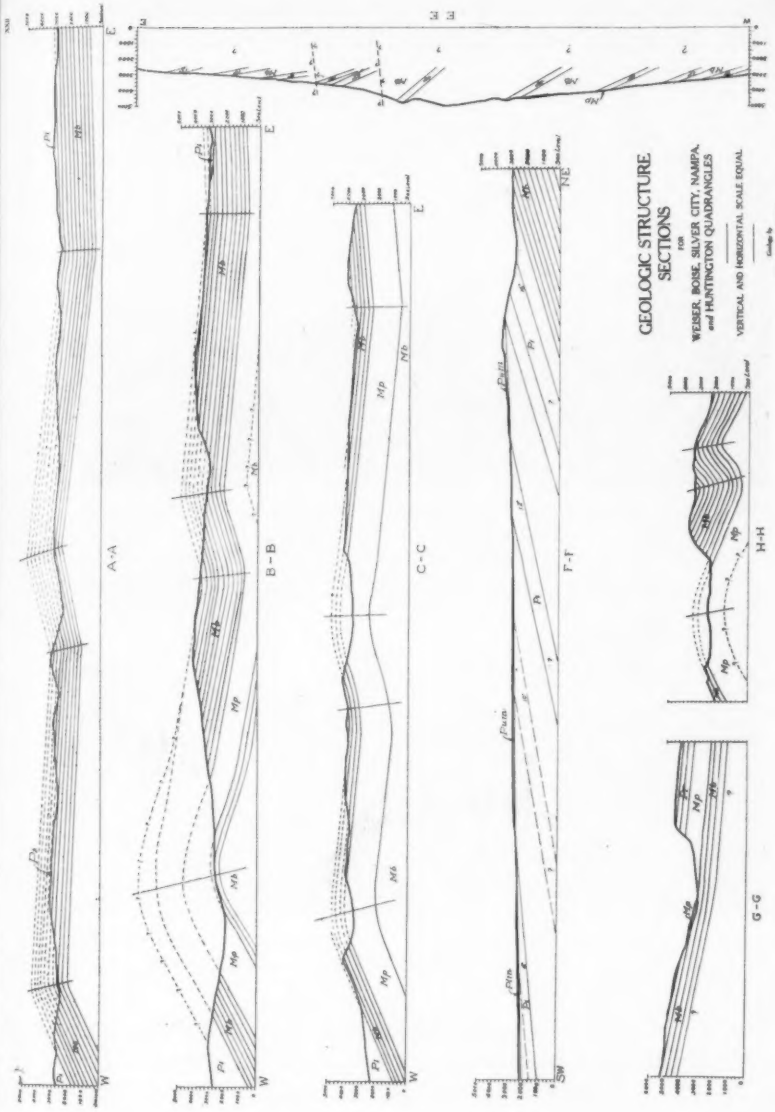


FIG. 12.—*Mb* is Columbia River basalt, *Pi* is Idaho formation, *Pum* is the Upper Mesa formation, *Plm* is the Lower Mesa formation, *Pr* is the rhyolite series, *Mp* is the Payette formation.

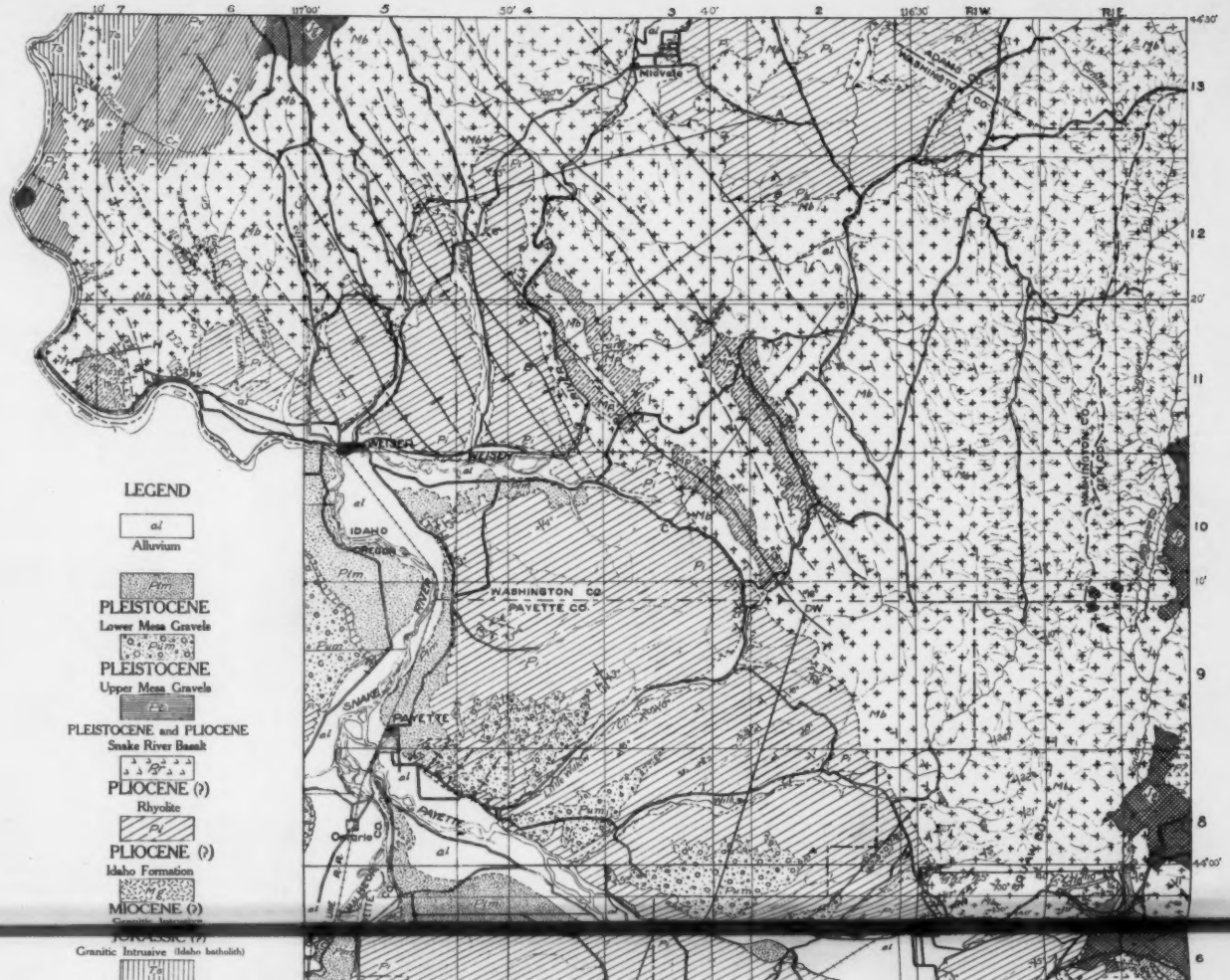
This section, carefully calculated, represents a thickness of basalt of more than 17,000 feet if duplication by faulting has not occurred

FIG. 14.—Looking northeast at the Payette formation in the Silver City quadrangle, dipping northeast under the Owyhee rhyolite which caps it.

FIG. 15.—Looking north on Little Squaw Creek at the Owyhee rhyolite overlying the Payette lake beds in the middle, and Columbia River basalt underlying the Payette in the foreground.

(see Fig. 12 *EE*). Concerning this area Lindgren[1] said, "The total thickness of the flows appears to amount to many thousand feet. The estimate is qualified by a possibility of duplication by faulting."

[1] "Description of the Boise Quadrangle," *op. cit.*, p. 4.


LEGEND
al
Alluvium
Plm
PLEISTOCENE
Lower Mesa Gravels
Pum
PLEISTOCENE
Upper Mesa Gravels
Tb
PLEISTOCENE and PLIOCENE
Snake River Basalt
Pr
PLIOCENE (?)
Rhyolite
Pi
PLIOCENE (?)
Idaho Formation
Mb
MIOCENE (?)
Granitic Intrusive (Idaho batholith)
Kg
Granitic Intrusive (Idaho batholith)
Nidvale
WEISER
IDAHO
WASHINGTON CO.
PAYETTE CO.
PAYETTE
Ontario
ADAMS CO.
WASHINGTON CO.
Plm
Pum
Pi
Mb
Kg
al
Tb
Pr
SNAKE
PAYETTE
DW
R5W
R4W
T13
T12
T11
T10
T9
T8
T7
44°30'
44°20'
44°10'
117°00'
30'
116°50'

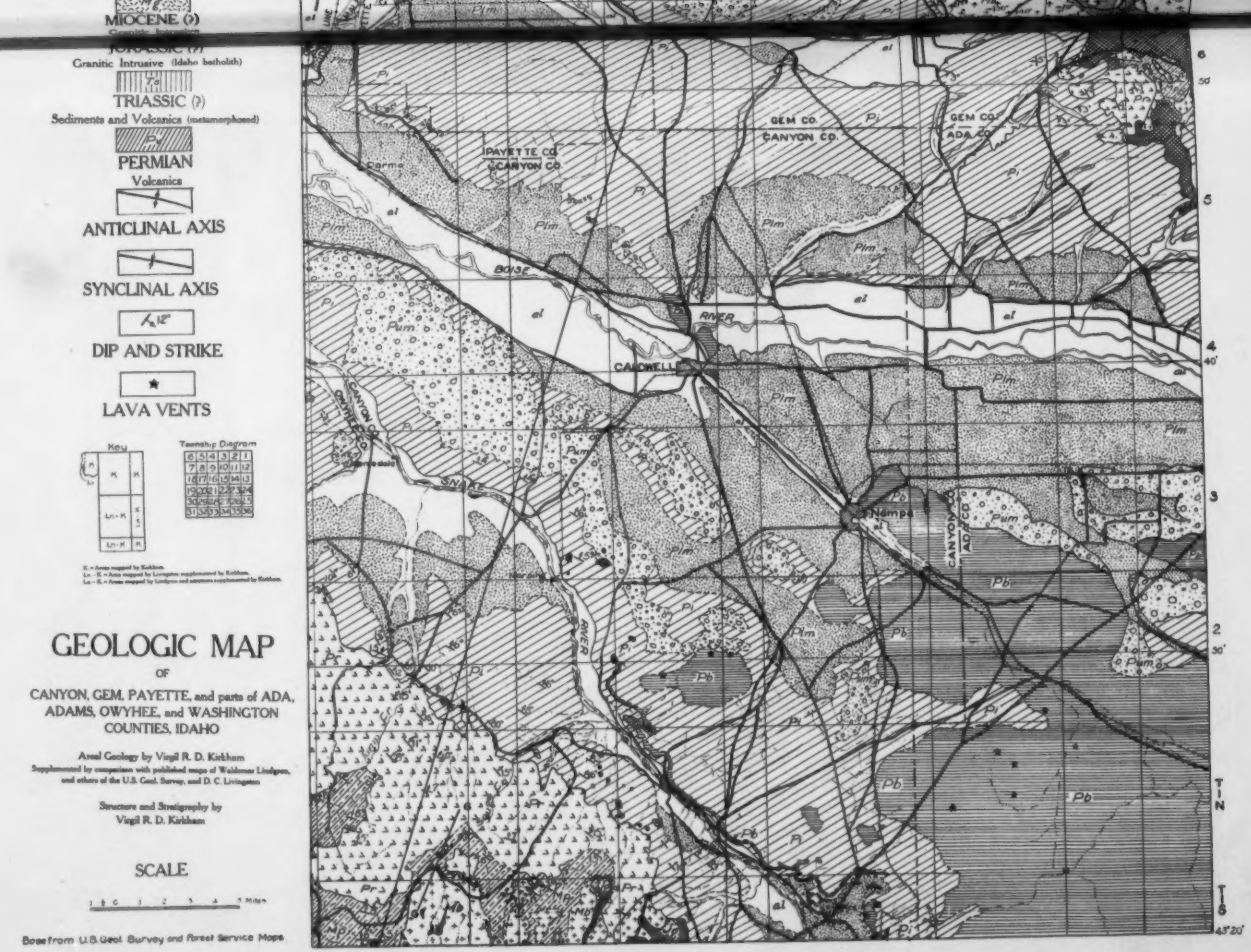

MIOCENE (?)
Granitic Intrusive
JURASSIC (?)
Granitic Intrusive (Idaho batholith)
TRIASSIC (?)
Sediments and Volcanics (metamorphosed)
PERMIAN
Volcanics
ANTICLINAL AXIS
SYNCLINAL AXIS
DIP AND STRIKE
LAVA VENTS
Key
Township Diagram
GEOLOGIC MAP
OF
CANYON, GEM, PAYETTE, and parts of ADA, ADAMS, OWYHEE, and WASHINGTON COUNTIES, IDAHO
Areal Geology by Virgil R. D. Kirkham
Supplemented by comparisons with published maps of Waldemar Lindgren, and others of the U.S. Geol. Survey, and D. C. Livingston
Structure and Stratigraphy by
Virgil R. D. Kirkham
SCALE
Base from U.S. Geol. Survey and Forest Service Maps
GEM CO.
CANYON CO.
PAYETTE CO.
ADA CO.
ADAMS CO.
WASHINGTON CO.
OWYHEE CO.
BOISE
RIVER
CALDWELL
NAMPA
SNAKE
Qal
Plm
Pum
Pb
Pl
Pr
T 1 N
R 3 W
R 2 W
R 1 W
R 1 E
43°30'

FIG. 13

He showed in his structure section BB the intermontane series dipping under the basalt, and the basin series overlying it. This basalt section was searched for evidence of strike faulting but conclusive evidence was not found. This great thickness extends from Payette River northward to the South Fork of Weiser River for a distance of approximately 35 miles.

At Cobb Siding west of Weiser, a measured thickness of 2,185 feet of Columbia River basalt separate the basin and intermontane beds (see Figs. 7, 12 *HH*).

On Weiser River 680 feet of basalt now separate the two sedimentary series (see Fig. 12 *BB*). There is evidence here that the basalt originally had a greater thickness.

In Crane Creek canyon at least 1,000 feet of basalt overlie the intermontane series and much additional lava has been eroded off the axis of the fold here. At another place south of Weiser River only 445 feet of basalt separate the two sedimentary series, while at another place, still farther south, 720 feet represent the thickness of basalt remaining over the intermontane series.

About 450 feet of basalt overlie the intermontane series on the west side of Paddock Valley and at least 1,000 feet overlie it east of the valley.

South of Payette River the thickness of basalt between the two series is as low as 300 feet at one place.

In summary, the stratigraphic interval between the basin and intermontane sediments is at almost every place very great. The time interval occupied by the outpouring of these great thicknesses of lava cannot be computed but must of course be estimated as of considerable length. An additional time interval of unknown duration must be assigned to the notable disconformity between the lavas and the upper series of sediments. The consideration of this evidence alone would seem to justify the separation of the two sedimentary groups into differently named formations.

LITHOLOGIC EVIDENCE

Lindgren,[1] in his first description of the basin beds, said:

> The latter consist chiefly of granitic light-colored sands, locally cemented by hot-springs deposits to hard sandstones (as at Table Mountain near Boise)

[1] "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*

or clayey semiconsolidated sandstones. Heavy masses of conglomerates and gravels begin to appear at Table Mountain, and reach their greatest development opposite the mouth of Boise River, in the high ridge extending in a westerly direction. Purely clayey deposits are rarer, occurring only in convenient sheltered locations near the shore line or in places where volcanic eruptions took place.

Describing them in Boise quadrangle,[1] he said:

They consist predominantly of light-gray arkose, granitic sands, and loose sandstones. The grains are angular or imperfectly rounded, and thus indicate rapid accumulation. . . . . The formation appears as light-gray or yellowish, flat-topped, barren sand hills with occasional clayey beds, and with a fairly distinct stratification. The sandstone is ordinarily only loosely cemented, though firmer sandstones occur at Table Rock. . . . . Excellent examples of false bedding cutting diagonally across the stratum were noted in the foothills a mile northeast of Boise.

Near Table Rock there are some gravels and conglomerates in the series. At the base lie alternating strata of coarse and fine, loose granitic sand and gravelly beds. Above, the beds are chiefly sandy, alternately loosely and firmly consolidated. North of Table Rock and 200 feet below the summit, lies a firmly consolidated stratum of sandy coarse gravel, the cobbles reaching the diameter of a foot or more. The summit of Table Rock is one continuous stratum of hard sandstone with very distinct lines of stratification and vertical jointing. The lower strata of sandstone are not continuous, but change in places to loosely consolidated material. . . . . The area extending from Dry Creek to the northwestern boundary is, on the whole, of very uniform character. The strata are light gray, consisting chiefly of loose granitic standstones, and form flat topped hills cut by many dry gulches. . . . . Thin strata of a compact white limestone occur north of Dry Creek, and on the point between the north and south forks of Willow Creek there is a layer of oolitic limestone. . . . . A bluff of hard sandstone caps the rhyolite on the north side of South Willow Creek.

In speaking of an 800-foot exposure southeast of Emmett, he said:

Its lower part consists of coarse granitic sand with occasional small pebbles of porphyry. In the upper part the sand is finer; there is a little more material in small streaks, and one 6-inch seam of coaly material was noted. . . . .

Similar soft sandstones of granitic origin, dipping gently westward overlie the basalt flow of Squaw Butte, north of the Payette. The strange fact that so little volcanic material is found among these deposits adjoining large volcanic areas has been emphasized in the description of the volcanic rock.

Lindgren,[2] in speaking of the basin beds which he calls the Payette and Idaho formations, said:

[1] "Description of the Boise Quadrangle," *op. cit.* [2] *Ibid.*, p. 2.

Practically, it is not possible to separate these two terranes, and in a large degree the same description applies to both. This is apparent since the material for both came from the same source—the great granite area of central Idaho; and further, a large part of the Idaho formation is simply Payette sediments worked over and redeposited. If clearly defined beach lines once existed they would soon have been obliterated owing to the soft and sandy character of the older, as well as of the younger, deposits.

It is obvious from this statement that Lindgren, like the writer, found the basin beds to be similar in lithologic character and indivisible on strictly lithologic grounds. He said further:

The majority of these beds are unquestionably of lacustrine origin. This is proved by their uniform appearance as well as by the very even stratification and the persistence of certain strata over large areas.

He found gypsiferous beds in the upper sediments and limestones in the lower beds. He recognized relatively small areas of fluvatile and delta deposits. He said:

In general, the strata consist of quartz sands with slight admixture of mica flakes, and thin strata of clays; for the most part they are light gray, buff, or nearly white in color. Strata in which clay is predominant probably make up only one-tenth of the whole amount of the lake bed beds. Occasionally thin interstratified conglomerates and small deposits of pebbles occur. These pebbles consist of granite-porphyry and quartz, more rarely of basalt and rhyolite. Toward the north end of the quadrangle[1] the strata are more sandy; angular quartz grains one-tenth of an inch, or less, in diameter are scattered through fine sediments showing imperfect assortment and rapid accumulation; rare and thin lignitic streaks appear in places and seem to be chiefly made up of carbonized grasses, indicating that at various times the lake was shallow and marshy.

In the region including the northern part of the Nampa quadrangle and southern part of the Weiser quadrangle he found, also, "thin intercalated white or gray tuffs which resist weathering so as to form slight breaks in the otherwise smooth steep hill slopes."

These tuffs he associated with the extrusion of Columbia River basalts in Squaw Creek quadrangle. The writer cannot accept this origin for these tuffs. It has been determined that the Squaw Butte lavas, and all Columbia River lavas in the map area, were extruded before any basin beds were deposited. The "tuff beds" are fine volcanic dust or ash layers which lie several thousand feet stratigraphically above the uppermost Columbia River basalt.

[1] He refers to the Nampa quadrangle.

Russell,[1] describing the basin rocks, said:

The rocks of the Payette formation are mainly sands, clays, and volcanic lapilli, with occasional beds of coarse gravel, especially near the bases of the bordering mountains. The strata have in many instances been consolidated, so as to form sandstone and soft shale, but to a great extent they are still soft, loose sands and slightly compacted sandy clays. . . . . I found the ordinary sedimentary beds to be interstratified with layers of white volcanic dust several feet in thickness.

Washburne,[2] in discussing the basin beds, said:

Below the surface, as is shown by the records of the wells, partly consolidated clay predominates markedly over coarser material, but on the surface of the ground sandy and pebbly beds are most conspicuous. Beds of fine conglomerate are common, the pebbles consisting principally of black chert, quartz, quartzite, and rhyolite. . . . . The pebbles are thoroughly water worn and of nearly uniform size in each bed, usually about one-fourth to one-half inch in diameter, although some beds contain pebbles 2 to 3 inches in diameter. The conglomerate is dark colored, generally from iron stain, and in cliffs it resembles flows of basalt, contrasting conspicuously with the light yellow sandy clay and sandstone with which it is interbedded.

The resemblance of this iron-stained conglomeratic grit to basalt is attested to by the fact that an area of this formation, lying chiefly in Secs. 4 and 5, T. 4 N., R. 2 E., is shown on the geologic maps of Boise folio[3] as basalt.

Buwalda said in his 1921 paper:[4]

These beds have been considered as lake beds heretofore, but the writer's studies indicate that they are probably in large part river flood plain and waste slope deposits and were laid down only in part in lakes.

Bryan, in describing basin beds, said:

The beds of the Payette formation are largely white or light gray and generally fine grained, but pebble beds and conglomerate also occur. The white sands and shales appear to be largely deposits of river flood plains or are partly consolidated ash of volcanic showers that buried the country and were little worked by streams.

In summary, all writers up to Buwalda appear to believe that practically all of the basin beds show undisputed evidence of lake origin. In general, they believed in the existence of widespread lakes

[1] "Geology and Water Resources of the Snake River Plains of Idaho," *op. cit.*, p. 50.

[2] *Op. cit.*, p. 27. [3] *Op. cit.*

[4] "Oil and Gas Possibilities of Eastern Oregon," *op. cit.*, p. 39.

in which these sediments were deposited. These lakes were supposed to have reached to certain levels which they attempted to establish. Bryan as well as Buwalda admitted small lakes but also strongly urged flood plains, deltas, and alluvial fans.

The writer is convinced that conditions varied greatly during the deposition of this great thickness of sediments. Careful detailed work in 1928 has shown that several characteristic strata are very widespread and are found in similar stratigraphic positions on each side of the downwarp. When these sediments were being deposited a rather far-reaching water body existed. At other horizons in the section it is plain that streams constituted the depositing agency. At other places fans and deltas have contributed much of the material, but in no case is there evidence for believing that fluviatile deposition will account for more of the material than lacustrine deposition.

The writer does not conceive of a great Lake Payette and a smaller Lake Idaho as do Lindgren, Russell, Washburne, and others, but visualizes temporary shallow lakes of varying sizes from time to to time alternating with intervals of desiccation.

The writer does not disagree with the descriptions by earlier workers of the character and lithology of the lake beds, but he would not generalize so greatly as others. Each method of deposition has a rather characteristic lithology and the section, at one place, may be eroded into a lake-bed horizon, but at another place a fluviatile horizon may be exposed. Here again, former workers have ignored the in-dipping attitude of the truncated strata. In walking a short distance toward the downwarp axis the observer may pass over alternating lacustrine and fluviatile materials.

Many of the "white volcanic ash" beds of earlier writers have been determined to be beds of diatomite which are now commercially worked outside of the area in Oregon.

The sands are chiefly uncemented but in some localities a sand stratum cemented by iron oxide crops out prominently for several miles. Although the outcrop is more obscure where uncemented, such a stratum can be traced from one cemented area to another one. At least three sandstone and two ash beds are valuable horizon markers, and are so extensive as to be valuable aids in locating

stratigraphic position over much of the area occupied by basin beds.

It is believed that a careful microscopic study of ash and diatomite beds will provide the key to the successful working out of the detailed stratigraphy of the basin beds.

If we turn now to the intermontane beds we find that their lithology is unlike that of the basin beds. Lindgren[1] in speaking of intermontane beds said:

> The basal part of the formation contains, at Horseshoe Bend, Jerusalem, and other localities along the Payette, small coal seams. In the clay accompanying these coal seams vegetable remains are of frequent occurrence. . . . . The plants were obtained near the base of the series, of which about 800 feet of alternating, fairly consolidated shale and sandstone are exposed.

Lindgren,[2] in another paper, in describing the intermontane beds, said, "The lower part of the series in the intermontane valleys, where the conditions for the formation of clayey beds were most favorable."

At another place he said:

> The Payette areas resting in the intermontane valleys are somewhat different from the main deposits in front of the range, and contain clay, tuffs, and coal beds; consequently evidences of plant life are better preserved than in the sandy beds. From strata near the coal was collected the flora upon which rests, in part, the evidence of the early Neocene age of the beds. The beds in the intermontane valleys are also often disturbed and uplifted.
>
> North of Marsh[3] the beds are sandy with subordinate layers of brown clayey tuff. They appear to dip below Squaw Butte basalt flows on the west and to be underlain by a basalt flow[4] on the east.

He said further:

> Southwest of Marsh, accumulations of lake deposits lie on the steep granitic slope. The beds which are often greatly disturbed, consist of sandstone, clay, thin coal seams, diatomaceous earth, fine gravels with basaltic pebbles, and brownish tuffs of volcanic glass, and are overlain by basalt. The beds are thus of somewhat earlier age than those on the west which cover the same basalts.

In speaking of another area of intermontane beds, he said:

> It consists of a series of well-consolidated sands and clay shales of marked fissility all dipping northwest, west or southwest at angles up to 25°. The top

[1] "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*, p. 633.

[2] "Description of the Boise Quadrangle," *op. cit.*

[3] Now Montour.

[4] The writer counted 16 underlying flows.

layer is an extremely coarse sandstone difficult to distinguish from the adjoining granite.

Lindgren,[1] in describing intermontane beds in Silver city quadrangle, said:

On the western side of the quadrangle the rocks consist of white shales, sandstones and compact clays. In general, the rocks are finer textured and more consolidated here than elsewhere, and they also extend higher up the mountain-side reaching an elevation of 5,300 feet.

That he recognized the difference between the intermontane beds and the basin beds in this quadrangle is indicated by his description of the latter on page 3:

On the eastern side of the range the conditions are different. Though the beds here are on the whole similar to those on the western side, they are less consolidated and consist of very soft, brilliantly white sandstones, changing in places to compact gypsiferous clay.

Further on he said:

If there had been only one period of deposition in the lake bed series, these deposits would certainly have been formed earlier than the Miocene plant beds of Rockville and Succor Creek.[2] That this can not be the case is shown by the different petrographic character and decided later fauna of the Snake River beds.[3]

Lindgren misinterpreted the stratigraphic position of the intermontane lake beds at Rockville and Succor Creek. In his text[4] and structure sections he shows them to be overlying the rhyolite and basalt; whereas work done by Buwalda and the writer in 1920 showed that their true position was under the rhyolite. Later work by the writer has conclusively proved that all of the area mapped as tuffs on Lindgren's areal map[5] and structure sections represents typical intermontane beds which underlie the rhyolite and overlie the Columbia River basalt in places (see Figs. 1 *HH*, 8, 12 *GG*, 13, 14, 15) and underlie the basalt in other places.

A study of the intermontane beds by the writer shows that they contain large amounts of ash, shale, and carbonaceous and coal

[1] Waldemar Lindgren and N. F. Drake, "Description of the Silver City Quadrangle," *U.S. Geol. Surv. Atlas Folio 104* (1904).

[2] These are intermontane beds.

[3] These are basin beds.

[4] "Description of the Silver City Quadrangle," *op. cit.*

[5] *Ibid.*

seams (see Fig. 7). Some of the latter approach a commercial grade but are relatively valueless because of distance to market.

This same series of tuffs and intermontane beds has been lately described by Bryan[1] under the name "tuffaceous conglomerate." He said:

> The oldest rocks within the area are of sedimentary origin and crop out in the Hole in the Ground and in a small area near the north end of the region shown on Plate 3. In both localities the beds lie beneath the Owyhee basalt, but in places in the Hole in the Ground a mass of porphyritic rhyolite intervenes between the two formations. . . . . The oldest rocks consist of alternating beds of partly consolidated conglomerate, arkosic sand, and sandy shale of a prevailing buff, light-brown, or green-brown color. Cobbles 6 inches in diameter are common, and a few boulders 1 to 2 feet in diameter were noted. . . . The pebbles and rock grains are all much weathered, and in consequence. determination of the character of the original rocks which supplied the material is correspondingly difficult. The greater part of the material consists of basalt, andesite, and similar igneous rocks, but fragments of quartzitic arkose and single grains of quartz and feldspar are present. The fine-grained beds are water-laid tuffs.

On his Plate X, he showed a yellow tuff member, a tuffaceous conglomerate member and a black shale member to be present in well logs. Bryan apparently recognized an age difference between these beds and the basin beds which he calls the Payette formation, or he would have assigned them also to the Payette formation.

Bryan's mapped outcrop of "tuffaceous conglomerate" lies at a point 10 miles north and 14 miles west of the western border of the map area where the intermontane beds crop out. The writer is confident that Bryan's "tuffaceous conglomerates," because of their lithology and stratigraphic position beneath the rhyolite, belong to the same series exposed in the southwestern portion of the map area.

The intermontane beds are best exposed in Weiser quadrangle on the eroded crests and limbs of anticlines in the overlying Columbia River basalt (see Figs. 11; 12 *BB*, *CC*, *HH;* 13). The lithology here is very similar in the various exposures and almost identical with that at Cobb Siding, and with that in Boise and Squaw Creek quadrangles. In all cases the material is well consolidated, the sandstone and ash are resistant, and the shales are well bedded and firm. Thick carbonaceous coaly seams are present at the same horizon

[1] Kirk Bryan, *op. cit.*, *Paper 587A* (January, 1929).

in each section. At Cobb they have been prospected extensively and approach a commercial grade, as do those in Boise and Silver City quadrangles.

In summary, it can be said that exposures of the intermontane beds in the map area show marked lithologic uniformity. They show a preponderance of ash and shale with relatively thin competent sandstone members. At every exposure occur characteristic ash beds at similar horizons. Carbonaceous seams sufficiently developed to stimulate prospecting for coal are present at essentially the same horizon in the series at each exposure. In some exposures in the Weiser quadrangle isolated basalt flows are interbedded with the sediments, but in no case do they make up more than a small part of the thickness. The intermontane beds are markedly more consolidated than the basin beds.

PALEOBOTANICAL EVIDENCE

So far as can be ascertained no collections were made and determined from the basin beds prior to those made by the writer in the summer of 1928. All of the fossil-bearing localities cited by Lindgren, Knowlton, and Chaney, in establishing the age of the Payette formation, are in intermontane beds which are separated from the basin beds by thick lava series as has been already shown. Inasmuch as all previously determined collections of flora made by Lindgren, Knowlton, and Chaney were from intermontane beds it is clear why their age should not be assigned to the basin beds which have now been proven to lie in a much higher stratigraphic position and above at least one unconformity.

Table I shows the list of species collected by the writer from various localities in the basin beds and determined by Dr. E. W. Berry of The Johns Hopkins University through the courtesy of the United States Geological Survey.

Locality No. 1 is stratigraphically about 1,000 feet above the Columbia River basalt, and is on Alkali Creek in Sec. 17, T. 9 N., R. 2 W., B. M. Leaves are in water-laid brownish diatomaceous clay.

Locality No. 2 is stratigraphically less than 200 feet above the Columbia River basalt and is about 15 miles northeast of Weiser on the North and South Highway, in Sec. 31, T. 13 N., R. 4 W., B. M.

Locality No. 3 is stratigraphically less than 150 feet above the Columbia River basalt and is about 8 miles northwest of Weiser, on Hog Creek, in Sec.

5, T. 11 N., R. 6 W., B. M. The material is lithologically similar to that at Locality No. 2.

Locality No. 4 is stratigraphically less than 500 feet above the Columbia River basalt, and is about 9 miles east of Weiser on the east side of Cove Creek, and ½ mile south of Weiser River. It is in Sec. 3, T. 10 N., R. 4 W., B. M. Ash predominates.

TABLE I

	Localities				
	1	2	3	4	5
Acer sp. (small leaf)					x
Betula sp.					x
Dryopteris idahoensis Knowlton	x				
Fagopsis longifolia (Lesquereus) Hallick		x			
Ficus washingtonensis Knowlton					x
Laurus similis Knowlton					x
Leueiscus scales (fish)		x			
Librocedrus sp.			x		
Myrica sp.			x		
Odostemon simplex (Newberry) Cockerell*		x			
Phyllites inexpectans Knowlton of Mascall†		x			
Pinus sp. (single needle)			x		
Platanus dissecta Lesquereus	x				
Potamogeton(?) sp.		x			
Quercus cognatus Knowlton					x
Quercus simulata Knowlton			x		
Quercus sp.		x			
Salix florissanti Knowlton and Cockerell					x
Salix inquirenda Knowlton					x
Typha(?) sp.		x			
Ulmus browelli		x			
Ulmus sp.				x	x

* Includes *Odostemon florissantensis* Cockerell.

† Probably includes *Phyllites payettensis* Knowlton of the Payette, described originally under preoccupied name *Phyllites olixurus*.

Locality No. 5 is stratigraphically less than 350 feet above the Columbia River basalt and is north of Cove Creek, and about 1½ miles southeast of Locality No. 4. It is in Sec. 12, T. 10 N., R. 4 W., B. M. The leaves are in a massive ledge-making ash or tuff member.

Locality No. 1 is about 30 miles across country from No. 3, and 27 miles from No. 2 which, in turn, is about 12 miles across country from No. 3. Geographically, it can be seen that the localities are rather closely associated. Stratigraphically the range is probably less than 900 feet.

Collections have been made from 18 localities in the intermontane beds. Lindgren,[1] in 1898, gave 4 localities; Knowlton,[2] in 1898, gave

[1] "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*

[2] "Fossil Plants of the Payette Formation," *op. cit.*

5 localities, 4 of which were those given by Lindgren; Lindgren,[1] in 1904, gave 2 more localities; Chaney,[2] in 1922, gave 6 localities, 1 of which is one of the original ones given by Lindgren in 1898. The writer in this paper gives 5 localities, 1 of which is a Chaney locality. The locations of former localities is given in the cited literature. The writer's localities are as follows:

Locality No. 1 is in Sec. 13, T. 11 N., R. 7 W., B. M., about 12 miles west of Weiser north of Snake River in a deep gulch. It underlies 2,200 feet of Columbia River basalt. The leaves were collected from a horizon less than 200 feet below the basalt. This is one of Chaney's localities.

Locality No. 2 is in Linson Valley, Sec. 12, T. 10 N., R. 3 W., about 25 miles by road northeast of Payette. These beds underlie several hundred feet of Columbia River basalt. The leaves are from a horizon about 450 feet below the lava.

Locality No. 3 is also in Linson Valley in Sec. 13, T. 10 N., R. 3 W., about 23 miles northeast of Payette. The beds underlie several hundred feet of Columbia River basalt. The horizon from which the leaves were collected lies about 600 feet below the basalt.

Locality No. 4 is also in Linson Valley, about 1 mile southeast of No. 3. The fossil-bearing horizon is the same as No. 2.

Locality No. 5 is also in Linson Valley, about 2 miles south of No. 4, and also under several hundred feet of Columbia River basalt.

Material was also collected from intermontane beds on Crane Creek, Weiser River, and Jump and Sucker creeks, but nothing has, as yet, been determined. The flora collected from all intermontane localities is listed in Table II.

The Payette flora, as first made known by Lindgren,[3] in 1898, showed only 13 species but, as it was described by Knowlton,[4] in 1898, included 32 species. In Lindgren's Silver City folio were added 12 more of which four were new forms, namely, *Ilex*, *Pteris*, and two *Quercus*. All the others were new to the Payette assemblage.

Chaney[5], in 1922, added 16 species,[6] 4 of which were new, bringing the total up to 60 species.

[1] *Op. cit.* [2] *Op. cit.*

[3] "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*

[4] "Fossil Plants of the Payette Formation," *op. cit.*

[5] *Op. cit.*

[6] Chaney says, *op. cit.*, page 215, that the previously described flora was increased by 17 species but gives a list of species on page 215 in which he lists *Platanus dissecta* previously listed by Lindgren on page 3, *Folio 104*.

TABLE II

	Lindgren, Knowlton							Chaney	Kirkham, Berry				
	1	2	3	4	5	6	7	6 Localities	1	2	3	4	5
Acacia (pod)						x							
Acer florisissanti Kirchner												x	
Acer gigas Chaney								x					
Acer trilobatum productum (?) Heer	x						x						
Acer n. sp.								x					
Acer sp.										x			
Acer fruits						x	x						
Aesculus simulata Chaney								x					
Almus carpinioides Lesquereux							x						
Betula aequalis(?) Lesquereux	x												
Betula angustifolia Newberry					x								
Betula n. sp.								x					
Betula fruit	x												
Cassia obtusa Knowlton	x												
Castanea castaneafolio (Unger) Knowlton										x		x	x
Castenea pulchella Knowlton													x
Castanea ungeri Heer							x						
Celastrus lindgreni Knowlton					x								
Celastrus sp.							x						
Dryopteris idahoense Knowlton		x											
Equisetum sp.					x								
Ficus underi Lesquereux				x									
Glyptostrobus europeans Chaney								x					
Ilex n. sp.							x						
Juglans nigella (?) Heer							x						
Juglans hesperia Knowlton		x											
Lampsilis valves									x				x
Laurus princeps Chaney								x					
Leuciscus scales (fish)									x				
Librocedrus sp.									x				
Liquidambar fruit										x			
Myrica lanceolota Knowlton				x									
Myrica(?) *idahoense* Knowlton	x												
Nyassa stones										x			
Odostemon simplex Chaney								x					
Phyllites flexuosus Knowlton	x												
Phyllites obscurus Knowlton	x												
Pinus knowltoni Chaney								x					
Pinus sp. fruit					x								
Platanus aspera(?) Newberry		x											
Platanus dissecta Lesquereux							x	x			x		x
Platanus sp.							x						
Populus eotremuloides Knowlton	x												
Populus lindgreni Knowlton	x												
Populus occidentalis Knowlton	x												
Potomogeten heterophylloides Berry									x				

TABLE II—*Continued*

	Lindgren, Knowlton							Chaney	Kirkham, Berry				
	1	2	3	4	5	6	7	6 Localities	1	2	3	4	5
Prunus n. sp.								x					
Pteris n. sp.							x						
Quercus clarensis Chaney								x					
Quercus cognatus Knowlton									x				
Quercus consimilis Newberry	x						x		x				
Quercus dayana Chaney								x					
Quercus idahoense Knowlton	x						x		x				
Quercus payettensis Knowlton					x								
Quercus simplex Knowlton		x											
Quercus simulata Knowlton	x						x		x		x		
Quercus n. sp.							x	x					
Quercus n. sp.							x						
Quercus sp.		x				x					x		
Rhus payettensis Knowlton	x												
Salix angusta Brongniart		x											
Salix californica Chaney								x					
Salix perplexa Chaney								x					
Sapindus oregonianus Chaney								x					
Sequoia affinis Lesquereux											x		x
Sequoia angustifolia Lesquereux	x						x						
Sequoia langsforfii (Brongniart) Heer													x
Sequoia cones		x											
Sequoia(?) sp.										x			
Taxodium sp.									x				
Trapa americana Knowlton					x								
Trapa(?) *occidentalis* Knowlton					x								
Ulmus californica Chaney								x					
Ulmus speciosa Newberry					x						x	x	x
Ulmus sp.						x							

Collections by the writer in 1928 from five localities, one of which was at Cobb Siding, one of Chaney's localities, were identified by Mr. E. W. Berry who discovered no new species but added 11 species new to the Payette assemblage. This brings the total to 71 species for the intermontane beds. The species not common to the Lindgren, Knowlton, and Chaney localities are readily determinable by consulting Table II. Of the 71 species only 13 are common to more than one locality. Chaney[1] says in his paper that 13 species in his collections were common to Knowlton's 32 species of 1898. Unfortunately he did not list his species by localities and thus there are now prob-

[1] *Op. cit.*, p. 215.

ably more than 13 species which are duplicated in the 18 localities represented.

Platanus dissecta is common to several localities of this area and is also a characteristic Miocene fossil of several widespread lake-bed regions. Chaney says, "Clearly it is a strong indication of the Miocene age of the Payette." Other important forms, such as *Ulmus californica* are also urged by Chaney as a valuable indicator of Miocene age. Twenty-three of the 71 species listed in the intermontane beds are common to the Latah flora as listed by Kirkham and Johnson.[1]

This large number of duplicates coupled with the similar stratigraphic position[2] and lithology suggests that the Latah and the intermontane beds of this area are near the same geologic horizon. The southernmost outcrop of the known Latah at Whitebird is only 85 miles from the northernmost intermontane bed of this area. The Latah extends for 200 miles northwest of Whitebird where it crops out at about 50 localities. The Latah formation seems to be of well-established Miocene age, and its similarity to these intermontane beds argues strongly for a similar age for them.

A study of the lists in Table I and Table II shows the basin beds and the intermontane beds have 13 genera, but only 5 species in common. The significant difference, however, between the two lists is the absence of *Sequoia* in the the basin beds of Table I.

That the intermontane flora is of Miocene age is now conceded by all workers. That the basin beds, on the other hand, contain Pliocene flora, is an idea presented here for the first time. Dr. Ralph W. Chaney has considered the evidence and says:[3]

> My studies of the Tertiary floras of the northern Great Basin, including southwestern Idaho, have led me to the conclusion that the presence or absence of Sequoia has a significant bearing on the fossil leaves.
>
> I find Sequoia in diminishing numbers in the Miocene and absent in the Pliocene in this region. The absence of Sequoia in the collections from beds above the basalt in the vicinity of Boise indicates that the age of these beds

[1] Virgil R. D. Kirkham and M. Melville Johnson, "The Latah Formation in Idaho," *Jour. Geol.*, Vol. XXXVII (1929), p. 483.

[2] The Latah formation underlies several hundred feet of Columbia River basalt, and is in turn underlain by a lower series of Columbia River basalt flows.

[3] Written communication.

may be tentatively referred to the Pliocene. A continuation of the studies under way by Mr. Dorf should entirely demonstrate the age of these deposits.

Dr. Erling Dorf, who has studied the evidence, says:[1]

The Tertiary lake beds in southwestern Idaho, lying above the Columbia River basalt, contain plant associations which appear to be Pliocene in age.

In summary, all previous collections have been from intermontane beds. The writer presents new evidence in the nature of flora from the basin beds, and collections from new localities in the intermontane beds, which augment that list to 71 species. Chaney and Dorf, paleobotanists most familiar with the Western and Great Basin provinces, consider the basin beds to be notably younger than the intermontane beds and very probably of Pliocene age.

INVERTEBRATE EVIDENCE

Gabb,[2] in 1866, described invertebrate fossils collected "from a fresh-water deposit on Snake River, Idaho Territory, on the road from Fort Boise to the Owyhee mining country collected by Mr. A. Taylor." The fauna consisted of *Melania taylori*, *Lithosia antiqua*, and a *Sphaerium* from Castle Creek, Idaho.

King,[3] in 1878, assigns the beds of this locality to the Pliocene. White,[4] in 1882, described *Latia dalli* from these deposits. Cope,[5] in 1883, named these beds the Idaho group and assigned to them an Early or Middle Pliocene age.

Lindgren,[6] in 1904, reported the finding of *Unio*, *Anodonta*, *Goniabasis*, *Ancylus*, *Corbicula*, *Lithasia antiqua*. Gabb, at a locality 3 miles west of Guffey in the basin beds and 1 mile west of Bernard Ferry, found banks of *Unio* shells. Washburne[7] reports finding *Carinifex* in that part of Oregon adjoining the Nampa quadrangle.

Dall,[8] in 1925, mentioned curious fresh-water forms that occur in lake beds in Serbia and Hungary, and said,

[1] Oral communication.

[2] W. M. Gabb, *Paleontology of California*, Vol. II, Part 2 (1866), Figs. 21–22.

[3] *Op. cit.*, p. 412. [4] *Op. cit.* [5] *Op. cit.*

[6] "Description of the Silver City Quadrangle," *op. cit.*, p. 3.

[7] *Op. cit.*

[8] W. H. Dall, "Discovery of a Balkan Fresh-Water Fauna in the Idaho Formation of Snake River Valley," *U.S. Geol. Surv., Prof. Paper 132G* (1924), p. 109.

They contain a number of genera strikingly different from any now living in the fresh waters of the globe, such as *Valenciennesia*, *Velutinopsis*, *Papyrotheca*, *Orgygoceras*, and *Boglivia*. There are also a few of the smaller forms like *Caspia* which are now found living or represented by close analogies in the Caspian Sea and Lake Baikal, both of which, it may be noted, are "relicten seen."

The chief interest of the present paper[1] lies in the discovery of some of these anomalous fresh-water genera in American lake beds of the Idaho formation, together with one or two curious forms not represented in Europe.

He listed twenty forms from the Idaho formation, of which 2 genera and 6 species are described by Dall as having a remarkable resemblance to marine genera. Several forms are similar or identical to those of the relic seas, Lake Baikal and Caspian Sea. All of these fossils were collected from localities in the basin beds and above the Owyhee rhyolite and Columbia River basalt.

Determinations from collections made by the writer from 5 new localities in the basin beds, in 1928, are as follows:

Loc. I, Sec. 2, T. 8 N., R. 5 W., B. M., about 2 miles east of Payette
Sphaerium sp. a. related to *S. idahoense* Meek but much smaller
Unio sp. near *U. californensis* Lea (recent)
Unio sp. near *U. oregonensis* Lea

Loc. II, Sec. 32, T. 9 N., R. 4 W., B. M., about 5 miles east of Payette
Sphaerium sp. b. n. sp. related to *S. idahoensis* Meek but much smaller. Near to *S. solidulum* Prime (recent), smaller and more elongate than *a*

Loc. III, Sec. 10, T. 12 N., R. 6 W., B. M., about 10 miles north of Weiser. The fossils were collected from a horizon less than 150 feet above the Columbia River basalt
Flumincola sp. near *F. nuttaliana* Lea
Sphaerium sp. aff. *S. idahoense* Meek (but thinner shell)
Unio sp.

Loc. IV, Sec. 29, T. 19 S., R. 44 E., Malheur County, Oregon, outside the map area but in basin beds
Flumincola (?) sp.
Sphaerium sp. (may be from the same horizon as Loc. III)
Unio sp.

Loc. V, about 5 miles northeast of Loc. IV
Flumincola sp. near *nuttalliana* Lea
Sphaerium sp. (same as the others)

All of the above forms were identified by Mr. W. C. Mansfield of the United States Geological Survey.

In summary, the invertebrate material collected from the basin

[1] Dall's.

beds, although not strictly definitive, indicates a Pliocene or later age for that series. Several species have a decidedly marine aspect. No invertebrate fossils except *Lampsilis* valves and traces of a large gastropod(?) reported by Dr. E. W. Berry from the writer's localities I and V have ever been reported from the intermontane beds.

VERTEBRATE EVIDENCE

Cope,[1] in 1883, listed vertebrate forms from the basin beds and called these beds the Idaho group which he assigned to a Middle or Lower Pliocene age. Lindgren,[2] in 1904, listed mammalian forms collected from basin beds in the Nampa quadrangle:

Equus sp., from three localities
Mastodon sp., from two localities
Procamelus, size of *P. major*
Castor n. sp.
Olor, size of *O. paleocygnus*
Pappichthys sp.
Cervus sp., smaller and more slender than *C. canadensis*

Lindgren,[3] speaking of basin beds, said:

Near Sommercamp ranch, at an elevation of 2,400 feet, bones encrusted with opal were found in sandstone and identified as *Protohippus*, a Miocene or Pliocene genus. In the adjoining Nampa and Bisuka quadrangles mammalian remains, principally *Equus* are frequent in these same beds.

In 1917, Merriam[4] said:

The Idaho formation is not as yet satisfactorily separated from the Payette, Eocene, or Miocene and from a Miocene or Pliocene stage which may intervene between the Payette and Idaho. It is, however, quite certain that there exists over a large area of southwestern Idaho a formation several hundred feet thick which may show evidence of deformation and which contains a fauna of a stage representing either the latest Pliocene or the earliest Pleistocene.

In 1918, he[5] said:

As nearly as can be judged the mammalian fauna of the Idaho represents a Pliocene stage later than any other Pliocene fauna of the Pacific Coast and Great Basin regions; with the possible exception of the Tulare Pliocene occurrence on the western border of the San Joaquin Valley.

[1] *Op. cit.*
[2] *Op. cit.*, p. 2.
[3] *Ibid.*, p. 3.
[4] *Op. cit.*, p. 432.
[5] John C. Merriam, "Fauna of the Idaho Formation (abstract)," *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), p. 162.

Buwalda,[1] in 1921, said "The Idaho formation, if Pliocene, was deposited very late in that epoch and may be Pleistocene in age."

Buwalda,[2] in 1923, said:

> The Poison Creek formation immediately overlying the rhyolite is made up of ash, clays, shales and sandstones very similar to the Payette but contains mammalian fossils indicating an age of Lower Pliocene or later. . . . . The Idaho formation lies in the middle and flatter part of the valley unconformably on the underlying formations. . . . . Mammalian remains indicate a Pleistocene age.

Buwalda,[3] in 1924, in speaking of fauna in basin beds, said:

> The second was found in the same section in strata overlying the rhyolite, probably disconformably, near Sands about 11 miles northeast of Rockville. The beds at both localities dip to the north beneath the nearly horizontal Idaho formation from which they are easily discriminated by their attitude and lithology. . . . . The age of the fauna is approximately lower Pliocene.

Hipparion teeth near *H. anthonyi* and rodent teeth constitute the most diagnostic material of the Sands fauna.

In discussing carp teeth from the basin beds Buwalda said,[4] in 1928, "The Idaho formation is either Pliocene or Pleistocene in age."

The writer collected vertebrate material from several localities in the basin beds in 1928, but much of it was valueless or undeterminable in character. Three new localities were established:

Loc. I, Sec. 27, T. 15 S., R. 46 E., in Oregon about 5 miles west of Weiser outside the map area at the "Slides"
Elephas columbi, Pleistocene age

Loc. II, Sec. 17, T. 17 S., R. 46 E., in Oregon, about 9 miles west of Payette, outside the map area and in Jacobsen Gulch
Elephas columbi, Pleistocene age
Camel
Elk or deer
Bison

Loc. III, Sec. 25, T. 12 N., R. 5 W., about 9 miles northeast of Weiser in a gully east of the North and South Highway. Abundant concretions containing fish bones of modern types and
Rhineostes or *Pimelodus*

[1] "Oil and Gas Possibilities of Eastern Oregon," *op. cit.*, p. 38.

[2] "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho, *op. cit.*, p. 3.

[3] "The Age of the Payette Formation and Old Erosion Surface in Idaho," *op. cit.*, p. 572.

[4] Written communication.

In speaking of this locality, Dr. J. W. Gidley of the National Museum says[1] these forms are not older than Eocene and may be as late as Pliocene or even Pleistocene. Mr. Gidley also identified the material from the other two localities:

Leusciscus (fish) scales were identified by Dr. E. W. Berry in the writer's paleobotanic locality No. 2, in the basin beds at Sec. 31, T. 13 N., R. 4 W., B. M.

All of the mammalian evidence points to a Pliocene or Pleistocene age for the basin beds.

The intermontane beds, on the other hand, yield very little vertebrate evidence. The only locality was established by Buwalda and the writer in 1920. It is located 1 mile north of Rockville in yellow lake beds west of the road.

Buwalda[2] said:

> The Rockville or lower fauna includes a proboscidean of the *Tetrabelodon* type, a species of Hypohippus resembling other forms in that genus from Middle and Upper Miocene formations of the Great Basin province, *Merycodus* sp., a large camel, a rhinoceros, fish bones, and fresh water shells. Probiscidean remains first occur in North America in the Middle Miocene; they are not abundant until Upper Miocene time. This fauna may represent the Middle Miocene but it is more probably of Upper Miocene age, and possibly even Lower Pliocene.

In 1928 the writer collected fragmentary material from this locality. Gidley[3] reported on it as follows, "Mammalian fauna belonging to the Miocene or early Pliocene period, a single fragment of a tooth is recognizable as representing one of the three-toed horses of this general age."

In summary, the vertebrate evidence from the basin beds supports the paleobotanic and invertebrate evidence of their Pliocene and Pleistocene age. Likewise the vertebrate evidence from the intermontane beds is in agreement with the paleobotanic evidence for their Middle or Upper Miocene age.

The Idaho formation by definition is Pliocene and Pleistocene in age, and the Payette formation by definition is Miocene in age. It is now proposed, in the light of foregoing evidence, to give the name

[1] Written communication.

[2] "The Age of the Payette Formation and Old Erosion Surfaces in Idaho," *op. cit.*, p. 572.

[3] Written communication.

"Idaho formation" to all basin beds in this area, and to give the name "Payette formation" to all intermontane beds in this area.

MIOCENE SERIES

PAYETTE FORMATION

Definition.—In the light of evidence presented in the preceding pages, this formation name is applied to the intermontane beds in the map area and contiguous areas in Idaho and Oregon. It consists of a lake bed and terrestrial series several hundred feet thick which generally occurs interbedded with the Columbia River basalt. At some places one or two thin basalt flows are included in the map symbol showing its outcrop. At a few places north of the downwarp it overlies the granite surfaces but at most places it overlies the Columbia River basalt. At some places it is immediatey overlain by the Owyhee rhyolite flows, but at most places it underlies the upper series of the Columbia River basalt. At several places erosion has cut through it to expose the underlying formation, usually the lower lava flows of the Columbia River basalt. The beds consist chiefly of well-consolidated ash, carbonaceous or coaly shale and sandstone. The age of the plant fossils is generally conceded by paleobotanists to be Middle or Upper Miocene. The mammalian fossils indicate a Middle or Upper Miocene, and possibly a Lower Pliocene age.

Distribution.—The Payette formation crops out only in intermontane valleys. It is exposed north of the basin at one locality in the Huntington quadrangle, at four localities in the Weiser quadrangle, at four localities in the Boise quadrangle, and at two localities in the Squaw Creek quadrangle. South of the downwarp it occurs at two localities in that part of the Silver City quadrangle lying within the map area. Its thickness averages about 1,000 feet over the entire area, and its lithology is very uniform. Readers wishing details concerning exact location of localities and thicknesses and characteristics for each are referred to the more detailed description following.

Locality descriptions.—The Weiser River locality lies in the southeast part of T. 12 N., R. 4 W., B. M., the eastern part of T. 11 N., R 4 W., B. M., and in the western part of T. 11 N., R. 3 W., B. M.,

along the valley of Weiser River and the lower part of Crane Creek where it is exposed in an eroded anticline. At this locality a thickness of 1,110 feet is exposed. This includes two interstratified basalt flows with a combined thickness of 285 feet. The total thickness of sediments here is 825 feet; this includes sandstone, ash, and carbonaceous shale. A detailed structure section was surveyed by plane table across this exposure.

The Linson Valley locality lies in Sec. 34, T. 11 N., R. 3 W., B. M., in the eastern part of T. 10 N., R. 3 W., B. M., in the southwestern part of T. 10 N., R. 2 W., and in Secs. 5 and 6 T. 9 N., R. 2 W., B. M., along the headwaters of Little Willow Creek where it is exposed in an eroded anticline (see Figs. 1, 9, 11, 12). The lower members of the formation are not exposed. There are exposed 395 feet of ash and shale exclusive of two interstratified basalt flows totaling 107 feet. A plane table structure section was surveyed across this exposure.

The Paddock Valley locality lies in the eastern part of T. 11 N., R. 3 W., B. M., in the southeastern part of T. 11 N., R. 2 W., B. M., and in the northwestern part of T. 10 N., R. 2 W., B. M., where it is exposed in an eroded anticline on the headwaters of Little Willow Creek. Much of this locality indicated by the map symbol is covered at certain times of the year by a large artificial lake. The amount of erosion here is similar to that in Linson Valley.

The Crane Creek locality lies chiefly in Secs. 35 and 36, T. 12 N., R. 3 W., B. M., and in Secs. 1, 2, and 11, T. 11 N., R. 3 W., B. M., where it is exposed in the deep canyon of Crane Creek across an anticline. The locality shows about 400 feet of ash, shale, and carbonaceous material, much of which is very coaly.

The Cobb locality lies in the west part of T. 11 N., R. 7 W., B. M., and extends southward across the Snake River into Oregon. It is exposed by erosion in an anticline (see Figs. 1, 7, 12). About 410 feet of lake beds are shown here and the base is not exposed. This section includes one interbedded lava flow 40 feet thick. Ash, shale, and coaly carbonaceous seams make up the section here as elsewhere.

The Montour locality lies in Secs. 14, 15, 21, 22, 23, and 29, T. 7 N., R. 1 E., B. M., on the east side of Squaw Creek Valley and north of Payette River. This locality shows a full section of the

formation in a monocline. Its thickness is 1,180 feet, and there are no interstratified lava flows in the ash and shale. The South Montour locality lies in Secs. 3, 4, 35, and 36, T. 7 N., R. 1 E., B. M., southeast of Montour in a monocline. A thickness of 800 feet is indicated here.

The Squaw Creek locality lies in the eastern part of T. 10 N., R. 1 E., along the sides of Squaw Creek Valley. The Squaw Butte locality includes five small outcrops in T. 8 N., R. 1 W., B. M., and two similar outcrops in T. 7 N., R. 1 W., B. M. These are interbedded with the Columbia River basalt and are tentatively assigned to the Payette formation.

The Rockville locality lies in T. 1 N., R. 4 and R. 5 W., B. M., and T. 1 S., Rs. 4 and 5 W., B. M., near the old deserted stage station shown as Rockville, on the Silver City topographic sheet and known locally as the Rocks. It is exposed in a monocline, and at least a thousand feet of this formation can be measured. Here, as elsewhere, ash, shale, and carbonaceous material predominate (see Figs. 1, 2, 3, 8, 12, 14, 15).

The Pearl locality lies in the southeastern part of T. 6 N., R. 1 E., B. M., near the old Pearl mining camp.

Structure.—All exposures are in monoclines where the dipping beds of the formations have been truncated by planation, except in the Weiser and Huntington quadrangles, where the exposures occur in undulations or anticlines on the monocline, the crests of which have been eroded. The monoclines represent either the limbs of the downwarp or the flanks of the great arches which flank the downwarp. The dip in some of these localities exceeds 16°, but in all cases it is consistent with the major structural features (see Figs. 1, 12, 13).

Origin.—During a period of quiescence in the extrusion of the Columbia River lavas, lakes, and swamps, caused probably by damming of old drainage lines by lava flows, became sites for the deposition of sediments. These were at times covered by ash showers which were widespread, and which are represented in all the Payette exposures. Deposition ceased with the recurrence of the lava extrusion.

Extent beyond the map area.—Exposures within the map area are separated by distances of more than 80 miles. South of the map area the Payette formation is known to extend for at least 20 miles. East

of the map area the Payette is known to extend to Idaho City, a distance of nearly 30 miles. Beds containing similar leaf fossils and some of the same species occur near Hailey, on Wet Creek, and near Salmon City, in intermontane valleys where they have been preserved by downfaulting north of the Snake River downwarp.

The Hailey locality is 100 miles east by air line from any Payette exposure in the map area. The Wet Creek area is 65 miles by air line farther east, and the Salmon City area is about 75 miles by air line, north of Wet Creek.

It seems that assigning these localities to the Payette is more hazardous than including the Latah which lies only 85 miles north of a Payette exposure in the map area and includes 23 of the 71 species listed for the Payette formation. Future work may possibly establish that the Latah and Payette formations and the formations exposed at Hailey, Wet Creek, and Salmon City all belong to a relatively long period of quiescence between lava extrusions.

PLIOCENE SERIES

IDAHO FORMATION

Definition.—In the light of evidence presented in preceding pages, this formation name is applied to all basin beds in the map area and in contiguous areas in Idaho and Oregon. It consists of lake beds and terrestrial beds which dip toward the downwarp axis and attain a thickness of several thousand feet in the middle of the basin. It includes all lake beds overlying the Columbia River basalt and Owyhee rhyolite but excludes the Pleistocene Upper Mesa and Lower Mesa formations and alluvium. Interbedded with the upper members is the Snake River basalt. The basal beds and upper beds are preponderantly sandy; but by far the greater thickness of the formation consists of light-colored shales. A few beds of volcanic ash and diatomite are conspicuous in the series. The basal sandstones are in places well cemented and resistant, but on the whole, the formation is poorly consolidated. Most of the formation is well stratified. The plant fossils, according to eminent paleobotanists, point to a Pliocene age. Invertebrate and vertebrate fossils indicate a Pliocene and Pleistocene age.

Distribution.—This formation occurs chiefly in the basin formed

by the slopes of basalt and rhyolite on the north side of the downwarp and the rhyolite on the south side of the downwarp in the map area. It underlies approximately the southwest half of the Weiser quadrangle, practically all of the Nampa quadrangle, the northeast half of that part of the Silver City quadrangle included in the area, about two-thirds of that part of the Boise quadrangle included in the map area, and probably all of that part of Bisuka quadrangle included in the map area, and the extreme southeastern part of the Huntington area. At places it is superficially masked by thin flows of Snake River basalt, by the gravels and silts of the Upper Mesa and Lower Mesa formations, and by alluvium.

Another area of the Idaho formation lies in the northeastern corner of the Weiser quadrangle and the northwestern corner of the Squaw Creek quadrangle. This exposure is separated from the main basin exposure by several miles of Columbia River basalt. Field relations indicate plainly, however, that the two exposures were once joined and that subsequent erosion on the anticlinorium between them has removed a strip of the Idaho formation from 6 to 15 miles wide. Structure sections, Figure 12 *AA*, *BB*, indicate the present relations of the two exposures. The northern exposure lies chiefly on the east flank of a wide and gentle syncline and extends for an unknown distance north of the area.

Thickness.—Many plane table sections were made across the strike of these dipping lake beds, with the following results:

The Little Squaw Creek section crossed 7,275 feet of beds in a horizontal distance of 59,000 feet. This was the greatest thickness measured on the south side of the downwarp. A section west of Jump Creek measured a thickness of 5,600 feet in 51,000 feet of horizontal distance. The Jump Creek section showed a thickness of 5,700 feet in 54,500 feet. The Poison Creek section showed 2,600 feet of beds in a distance of 11,000 feet (see Figs. 4 and 5). The Sommercamp section showed 3,400 feet of beds in a distance of 14,000 feet. All of these sections started at the rhyolite and were surveyed along the dip towards the axis of the downwarp. Each one was extended as far as outcrops were measureable. Nearly all the dips were obtained by the plane table stadia method, and thicknesses were calculated with the use of logarithms.

On the north side of the downwarp the sections were longer and the thicknesses arrived at were greater than those south of the axis. The Haarman section (see Fig. 1), starting at the head of Alkali Creek, extended 83,725 feet or 15.6 miles, and crossed 10,800 feet of beds. A section starting at the basalt and ex-

tending down Little Willow Creek was 68,000 feet long. The calculated thickness of the beds crossed gave the maximum figure measured in the map area of 18,633 feet. These thicknesses were obtained by the planetable stadia method also.

Whether or not these immense thicknesses are correct is impossible to say. It is obvious, however, that the thicknesses assigned by Lindgren[1] and other earlier workers were far from accurate, and were based on the erroneous idea that the beds were deposited in a previously formed great basin, and now lie approximately horizontally. This relationship is shown by Lindgren[2] on structure sections AA and BB of the Silver City folio.

That the beds extend far below sea level and that they have been deposited in a subsiding area is attested by Washburne's[3] statement wherein he said:

> The minimum thickness of the Payette and Idaho formations at Ontario, Oregon, is 4,000 feet, the depth of the Ontario gas well, to which should be added about 200 feet of higher strata exposed in the bluffs northwest of the well. The minimum thickness of these formations is therefore about 4,200 feet; the true thickness may be much greater. This figure places the bottom of the Payette formation below sea level under much of the Snake River Valley. At the bottom of the Ontario well the Payette formation is 1,839 feet below sea level as determined by comparing the depth of the well with a near-by United States Geological Survey bench mark.

The "Payette formation" mentioned by Washburne is included in the Idaho formation as here defined. The Ontario well lies within the map area across the Snake River from Payette, and toward the axis of the downwarp which lies several miles to the south. Wells at Payette 1,800 feet deep are still in the Idaho formation and a well at Weiser 1,500 feet deep was still in Idaho sediments, although only 4 miles from the contact where the basalt dips under the lake beds. The Haarman well on Alkali Creek is reported to be 1,875 feet deep. It is still in the Idaho formation although it is less than 2 miles distant from the contact where the basalt dips under the lake beds.

Wells as deep as 1,700 feet, and still in Idaho formation, are located south of Snake River within 2 miles of the contact of the rhyolite where it dips under the lake beds. The well data offer persuasive

[1] "Description of the Boise Quadrangle," *op. cit.*

[2] "Description of the Silver City Quadrangle," *op. cit.*

[3] *Op. cit.*, p. 29.

argument for accepting the greater figures arrived at by planetable traverses and calculation.

Structure.—The Idaho formation lies in two synclinal depressions. The greater one, extending transversely across the map area, is described in this paper as the Snake River downwarp. The minor one is the Midvale syncline in the northeast part of the Weiser sheet.

In the downwarp the Idaho beds dip inward to the axis from the lavas which flank the Snake River Valley (see Figs. 1, 12 *FF*, 13). The dips of the upper members are progressively less toward the axis of the downwarp where the beds become practically horizontal. The steepest dip south of the axis was nearest the rhyolite, and measured 16.° Dips as low as 4° were measured north of Snake River in Nampa quadrangle. The steepest dip north of the axis was nearest the basalt and measured 29°. Dips as low as 3° were measured near Payette, about 15 miles from the basalt contact.

In Weiser quadrangle and the Huntington area the Idaho formation is folded into several closely-spaced, practically parallel, plunging asymmetric folds which affect equally the underlying Columbia River basalt and the interbedded Payette. An examination of the areal map of Weiser quadrangle (see Fig. 13) shows the axes of these structures and the relations of the Idaho formation to the structure. Gentle flexures, possibly due to differential compaction rather than tangential pressure, are obscurely indicated at a few points in the Weiser quadrangle and in the region in Oregon contiguous to the Nampa quadrangle.

The practically unconsolidated sediments lack horizon markers. In all cases where the planetable was used, the reversals of the regional dip toward the downwarp axis were less than 100 feet per mile.

In the Midvale syncline the Idaho formation lies on the eastern flank and dips southwest to the axis at angles of less than 4°.

Origin.—The basal members of the formation were deposited on the flat-lying Columbia River basalt. Soon thereafter subsidence began and in the basin which resulted, deposition was continued. Subsidence also continued and is known to have lasted until after the deposition of the late Pleistocene Lower Mesa formation and may actually be in progress at the present time. The deposition was

chiefly in ephemeral lakes, some of which were relatively widespread, while others were local in character. Intervals of desiccation were marked by flood-plain deposits. Alluvial fans and deltaic deposits were rare but are indicated at a few places. Widespread strata of volcanic ash make up a small part of the thickness.

Extent beyond the map area.—The formation covers a large part of the map area and extends into Oregon for an unknown distance. That it underlies great areas of the downwarp to the east in Idaho is revealed by the deep canyon of the Snake River which has cut through the overlying Snake River basalt and into the Idaho formation for several hundred feet. In Bisuka quadrangle the outcrop becomes narrower and the lateral extent is unknown. These beds are well exposed at Castle Creek, Oreana, Grandview, Glenns Ferry, Hammett, Hagerman, and Melon Valley where the Snake River basalt has been removed by erosion. At Melon Valley, 115 miles by air line from the edge of the map area, where they overlie the rhyolite they gradually pinch out until, at a point a few miles east of Buhl, they are no longer present and the thick flows of Snake River basalt immediately overlie the rhyolite. This relationship is maintained until the rhyolite is no longer visible were the Snake River has not completely cut through the overlying Snake River basalt.

That the formation is more extensive where the downwarping was stronger is a logical inference and the greatest thicknesses and greatest width are probably represented within the map area or farther west in Oregon. The portions of the formation lying in the Midvale syncline extend to an unknown distance northward from the map area.

THE ADIRONDACK MAGMATIC STEM[1]

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ABSTRACT

The intrusive rocks of the Adirondacks vary from anorthosite and gabbro, through various syenitic and granosyenitic types, to granite. The problem of the origin of the anorthosites is considered, and the possibility of their concentration by a combination of gravitative crystal sorting in a deep-seated chamber and subsequent filtration-differentiation at the site of their emplacement higher up in the crust is discussed. The syenitic and granitic rocks are interpreted as the result of differentiation with low fractionation, and successive intrusion. A study of the rocks of the Adirondack series, and comparisons with other rock stems, is made, and it is concluded that the Adirondack rocks may be ascribed to a pyroxene (diopsidic) line of descent in the early and part of the intermediate stages of differentiation, and to a hornblende line of descent in the latter part of the intermediate and in the granitic stages. A characteristic feature of the differentiation is the relatively prolonged delay in the formation and separation of quartz. Differentiation is believed to have proceeded in much drier magmas than those of the more hornblendic Coast Range–Sierra Nevada series, and in slightly wetter magmas than the more completely pyroxenic Bergen-Jotun or Christiania stems.

INTRODUCTION

The major petrologic features of the various facies of the pre-Cambrian igneous rocks of the Adirondack province of New York state were early set forth by Cushing, Kemp, and Smyth. Supplemental data have since been added by Alling, Balk, Buddington, Dale, Gillson, Martin, Miller, and Newland.

In most of the published work the rocks (exclusive of anorthosite and gabbro) have been described as varieties of syenite, granosyenite or quartz syenite, and granite. Cushing[2] early called attention to the similarities with the labradorite and monzonite facies of the Ekersund-Soggendal area in Norway and with the akerites of the Christiania district. Alling[3] has recently emphasized the similarities of certain facies of the Adirondack rocks to some of those of the Christiania series, and has accordingly used the terms laurvikite, nordmarkite, and quartz nordmarkite for what he considers the equivalent Adirondack types.

[1] Published by permission of the Director, New York State Museum.

[2] H. P. Cushing, *Bull. Geol. Soc. Amer.*, Vol. X, pp. 179–92; and *N.Y. State Mus. Bull. 95* (1905), pp. 338–40.

[3] J. F. Kemp and H. L. Alling, "Geology of the Ausable Quadrangle," *N.Y. State Mus. Bull. 261* (1925), pp. 42–55.

The writer in six field seasons between 1916 and 1929 completed for the New York State Museum the geologic mapping of about 1,000 square miles in the northwest Adirondacks. The recent publication of Bowen's[1] extended treatise on fractional crystallization as a hypothesis to explain most of the features of magmatic differentiation has led the writer to attempt to apply the principles therein set forth to the problem of the genetic relationships of the Adirondack igneous rock types, practically all of which are exposed in the area studied.

GEOLOGIC CHARACTERS

The geology of about half the area of the Adirondacks has been mapped on the scale of a mile to the inch. A study of these maps, which necessarily can give only a reconnaissance of the problem, yields the following data. Basic syenite and syenite appear to be restricted to the northern and northwestern Adirondacks. Augite–hypersthene syenite has been found almost wholly on the Lake Bonaparte and Long Lake quadrangles. Augite and hornblende syenites, with less than 10 per cent quartz, are found in the Lake Bonaparte, Lowville, Antwerp, Long Lake, Lake Placid, Blue Mountain, Ausable, and Port Henry areas. In the southern and western Adirondacks, however, augite, hornblende, and hornblende–biotite quartz syenite and granosyenite, and hornblende–biotite granite, are the predominant facies. The granite with quartz ranging from 30 to 40 per cent is roughly equal in amount to the granosyenites with 25 per cent or less of quartz. Large bodies of granite, however, also occur in the northern Adirondacks, and the Lyon Mountain quadrangle shows granite almost wholly. No true diorite bodies have been found in the main body of the Adirondacks, and quartz diorite only in small masses on the Lake Pleasant and Luzerne quadrangles.

There has been much discussion as to whether there are granites of two markedly different ages in the Adirondacks, one corresponding to the Laurentian, the other to the Algoman. It is the so-called Algoman[2] rocks only which are here considered. The oldest rocks of this series exposed are anorthosite and gabbro. These are intruded

[1] N. L. Bowen, *The Evolution of the Igneous Rocks* (Princeton: Princeton University Press, 1928).

[2] Kemp and Alling, *op. cit.*, pp. 58–59.

by the syenitic types, that are in turn intruded by granite. All are cut by occasional dikes and small stocks of diabase (hyperite). In many cases what appear to be younger intrusive lenses of gabbro are cut by granite pegmatite veins, and the relative ages of many of the gabbro masses with respect to the syenitic-granitic rocks are in dispute. In the Grenville belt of the northwest Adirondacks there are many large sills of gabbro definitely older than the syenitic and granitic rocks.[1] Balk also interprets the gabbro masses in the area studied by him as old as or older than the syenitic-granitic series.

The structural relations of the intrusives in the northwest Adirondacks have been discussed by Buddington[2] and of the anorthosites and adjoining syenitic rocks of the core by Balk.[3] Buddington has suggested the possibility that the great Adirondack complex of intrusives may be interpreted in considerable part as the result of successive intrusions, over a long period of time, of differentiated magma in the form of sills, laccoliths, and phacoliths with attendant crosscutting bodies. The complex frequently shows a pronounced banding with variation in composition and sharp boundaries, but with brecciation phenomena lacking or at a minimum. In many cases one mass could not have been completely consolidated before the next was intruded. There has also, doubtless, been some differentiation in place arising from gravity sorting of crystals and especially filter-pressing, which has given rise to some of the moderate and small-scale banding within the syenitic and granitic types.

Balk interprets the anorthosite of the eastern Adirondacks as "very probably of lenticular shape, tilted to the northeast at 20° to 30°, and with a longest horizontal axis running northwest-southeast. The maximum thickness is estimated at twelve miles, the minimum at less than ten miles." Of the associated syenitic series he writes: "The syenitic rocks in the vicinity of the anorthosite do not form a massif of a definite shape. Extending outwards from the central intrusive, they surround it as an extensive system of sills, inserted con-

[1] Robert Balk, "Structural Survey of the Adirondack Anorthosite," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 289–302.

[2] A. F. Buddington, "Granite Phacoliths and Their Associated Contact Zones in the Northwest Adirondacks," *N.Y. State Mus. Bull. 281* (1929), pp. 86–94.

[3] *Op. cit.*

cordantly into Grenville strata. Cross-cutting contacts on a large scale have never been observed."

In the northwest Adirondacks the complex has been subjected to mountain-making forces, and the whole folded and deformed. Belts[1] of cataclastic, protoclastic, and aclastic foliation are found in the syenitic-granitic rocks.

MINERALOGY

The major minerals of the common syenite-granite types of Adirondack intrusives are given in Table I. These are taken largely

TABLE I

MODE OF TYPICAL ADIRONDACK INTRUSIVES

	Microperthite	Orthoclase or Microcline	Oligoclase	Quartz	Hypersthene	Monoclinic Pyroxene	Hornblende	Biotite	Magnetite
1	.....	56.1	.....	2.9	10.6	11.5	9.7	.....	6.6
2	50	16	16	6	1.0	4.5	2	.....	1.5
3	76	.....	1.5	11	.....	9	0.5	.....	1.5
4	65.7	.....	13.6	2.8	.....	.....	14.8	.....	2.9
5	54.7	.....	22	10.2	.....	.....	10.2	.....	2.1
6	52	4.5	11	16	4	5	5	.....	1
7	46	12.3	11.5	16	.....	9	3	.....	1.6
8	50.7	9	12	16.5	.....	.....	7.7	1.0	1.5
9	40	15.7	9	23	.....	.....	7.3	2	1.5
10	20	28	10	33	.....	.....	3	3	1.2
11	32	16	7.7	34.5	.....	.....	5	2.5	1
12	46	6.5	9	30.5	.....	.....	1	1.5	2.5
13	54.5	6	2	34	.....	.....	0.75	0.75	0.6

1. Augite–hypersthene syenite, near Raquette Falls, Long Lake.
2. Augite syenite, average of 4 analyses, Lake Placid quadrangle.
3. Augite syenite, average of 4 analyses, Lowville quadrangle.
4. Hornblende syenite, Litchfield Park, Long Lake quadrangle.
5. Quartzose hornblende syenite, Litchfield Park, Long Lake quadrangle. Almost the same as average of 3 from Lowville quadrangle.
6. Augite–hypersthene quartz syenite, average of 10.
7. Augite quartz syenite, average of 14.
8. Hornblende quartz syenite, average of 12.
9. Hornblende–biotite granosyenite, average of 21.
10. Hornblende–biotite granite porphyry, average of 15.
11. Hornblende–biotite granite, average of 31.
12. Granite, Lyon Mountain, average of 13.
13. Alaskitic granite (less than 2 per cent Hb+Bi), average of 8.

[1] Buddington, "Foliation of the Gneissoid Syenite–Granite Complex of Lewis County, New York," *N.Y. State Mus., 14th Ann. Rept.* (1919), pp. 101–10; and W. J. Miller, "Origin of Foliation in the Precambric Rocks of Northern New York," *Jour. Geol.*, Vol. XXIV (1916), pp. 587–619.

from data given by W. J. Miller in his many quadrangle reports and from the report by Cushing on Long Lake quadrangle. Good data on the mode of the augite syenite and basic syenite are lacking, because they are often so coarse grained or porphyritic as to be poorly adapted for the application of the Rosiwal method. In general, the percentage of ferromagnesian minerals decreases and quartz increases in passing from basic syenite to granite. But, in particular, augite, hypersthene, and hornblende may vary widely in relative proportions to each other, with quartz constant in the granosyenites, and the total amount of hornblende and biotite may vary widely in the granites, with quartz remaining constant.

The monoclinic pyroxene is usually emerald green, and has been considered by Kemp and Alling[1] to be a soda-bearing variety justifying the term aegirite-augite.

CHEMICAL COMPOSITION

The average of chemical analyses and norms of rock types belonging to the Adirondack magmatic stem is given in the accompanying tables. The chemical analyses of the rocks associated with the magnetite iron ore deposits at Mineville, made by M. K. Adams for Kemp,[2] are exceptional in their character and were not included. Dr. Robert Balk generously permitted the writer to study six unpublished analyses made for him in connection with his work on the anorthosites. All of these, except that of a gabbro, are of unusual types representing gradations or intermixture of anorthositic and syenitic matter. An average of two analyses of the more siliceous members is given as No. 13. Certain minor constituents given for a number of the analyses have been omitted, which explains the low summation for some of the averages.

INTERRELATIONS OF ANORTHOSITE, GABBRO, AND SYENITE-GRANITE SERIES

The writer has studied the entire sequence of rocks from anorthosite (a mass a square mile in area occurs south of Fargo in the Antwerp quadrangle) through gabbro and syenite to granite in the

[1] *Op. cit.*, p. 44.

[2] J. F. Kemp and R. Ruedemann, "Elizabethtown and Port Henry Quadrangles," *N.Y. State Mus. Bull. 138* (1910).

northwest Adirondacks, and believes that they have had a common origin.

Balk[1] has made a thorough study of the structural relations of the anorthosites and the syenitic rocks in the eastern Adirondacks and in a very clear statement has given the following interpretation of their origin:

> A "parent magma" in which appreciable quantities of solid labradorite and also ferromagnesian minerals were already suspended has been intruded into the Grenville formation from the north and northeast obliquely upward to the south and southwest. The farther the magma advanced, the narrower grew the channels along which it moved, the greater became the effect of friction between the magma and the relatively stationary walls, as well as between the magma and its suspended crystals. The increasing friction must have retarded the motion of the suspended crystals; it has gradually crowded them together and reduced the mobility of these gathering crystal masses. The liquid portion of the parent magma (syenite), however, has continued to move on, probably as far as 10 or 20 miles into the Grenville strata, always conformable to gliding planes of the (partly liquified) sediments. . . . . The gabbros appear to have originated through local accumulation of basic schlieren in the parent magma, ... the syenite plays the part of a mother-liquor. As such it is by far the most generally intrusive rock . . . . syenites frequently grade into normal gneissoid granites. These granitic sills reach far into Grenville areas.

In an unpublished manuscript from which the writer is permitted to quote, Balk writes, "According to the evidence of many good exposures the bulk of the gabbros have formed as segregations in the same magma which has differentiated simultaneously into anorthosite and gabbro . . . . all contact observations . . . . indicate that the gabbros are of spherical shape." He also writes of amphibolitic gabbro masses occurring as lens-shaped bodies.

Bowen[2] had previously suggested that anorthosites may result from the co-operation of two agencies of concentration, gravity sorting and squeezing out of the residual liquid or filter pressing. The writer herewith attempts to apply this conception to the problem of the Adirondack anorthosites, assuming the common origin of anorthosites, gabbro, syenite, and granite.

To start with, we assume that a basaltic liquid forms a huge mass in the crust of the earth at levels considerably below that of the sub-

[1] Robert Balk, *op. cit.*

[2] "Differentiation by Deformation," *Proc. Nat. Acad. Sci.*, Vol. VI (1920), p. 160.

sequent position of emplacement of the differentiates. Crystallization sets in and, at the first stage, plagioclase, olivine, and a little titaniferous magnetite separate and are soon joined by pyroxene. The original magma may have been undersaturated, or else the early crystallized olivine reacted with the liquid on cooling to form pyroxene; for quartz, in general, does not appear until a late stage in the Adirondack series. In these early stages, the plagioclase tends to rise a bit, and the mafic minerals sink, so that there is an accumulation of plagioclase in the upper part of the chamber. Grout[1] has described an anorthosite zone in the upper part of the Pigeon Point sill whose origin he ascribes to such a rise and accumulation of plagioclase in the early stages of crystallization. Goldschmidt[2] similarly ascribes the origin of the anorthosites of the Bergen-Jotun rock series to the rise of plagioclase crystals and their accumulation in the early stages of crystallization.

Bowen[3] has given a detailed discussion of how a normal plateau type of magma (50 per cent $Ab_{28}An_{72}$) of the Hebrides may be changed to a less basic basalt (about 43 per cent $Ab_{40}An_{60}$) through the crystallization of a mixture of 53 per cent plagioclase ($Ab_{37}An_{63}$), 27 per cent olivine, and 12 per cent diopside and magnetite, to the extent of about one-half the magma.

Using Bowen's method, the writer has found that the average basic syenite of the Adirondacks similar to No. 6, Table II, with 54 per cent SiO_2, may be obtained from the average basalt given in Daly's[4] tables by subtraction from it of a crystal aggregate consisting of about 50 per cent plagioclase ($Ab_{28}An_{72}$), 24 per cent diopside, 4 per cent hypersthene, 12 per cent olivine, 9.9 per cent magnetite, and 1 per cent of orthoclase. A trifle over half the magma would have to be crystallized. Similarly the average augite syenite (Table II, No. 7) of the Adirondacks may be derived from the average basalt through the subtraction by crystallization of about two-thirds of the magma; the crystal aggregate consisting of about 50 per cent

[1] F. F. Grout, *Bull. Geol. Soc. Amer.*, Vol. XXXIX (1928), pp. 555–77.

[2] V. M. Goldschmidt, "Stammestypen der Eruptivgesteine," *Kristiania, Videns. Skr. I. Mat.-Naturv. Kl.*, No. 10 (1922), p. 9.

[3] *The Evolution of the Igneous Rocks*, pp. 74–78.

[4] R. A. Daly, *Igneous Rocks and Their Origin* (1914), p. 27, Analysis No. 53.

plagioclase ($Ab_{24}An_{76}$), 21 per cent diopside, 7 per cent hypersthene, 12 per cent olivine, and 10 per cent magnetite. There is general agreement that the orthoclase molecule, which appears to the extent of over 6 per cent in the anorthosites, exists in part in solid solution in the plagioclase. This would result in increasing the total percentage of feldspar and slightly decreasing the norm ratio of the anorthite to the albite in the plagioclase, for the figures just given.

The specific gravity of the basic syenite (monzodiorite) is about 2.90, and of the augite syenite (augite monzonite) 2.77. The information available seems to indicate that labradorite would not sink

TABLE II

AVERAGE CHEMICAL ANALYSES OF ADIRONDACK IGNEOUS ROCK TYPES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	54.55	51.62	54.16	46.48	50.66	54.10	58.70	62.37	63.63	65.65	67.34	67.61	67.89	70.21	76.31
Al_2O_3	26.48	24.45	22.92	15.62	17.51	17.45	17.95	17.35	16.25	16.84	14.94	15.42	14.60	14.09	12.61
Fe_2O_3	1.02	1.65	1.20	2.71	5.57	4.53	3.96	2.44	2.71	2.56	1.92	1.29	1.70	1.56	.96
FeO	.62	5.30	2.78	11.94	6.21	6.47	4.34	4.05	2.77	2.02	2.75	2.72	3.62	1.85	.53
MgO	.72	1.21	2.32	6.40	2.92	2.33	1.18	.86	1.26	.13	.60	.50	.59	.42	.27
CaO	10.34	9.97	10.39	8.66	7.66	6.17	4.59	3.32	3.07	2.47	2.26	2.25	2.17	1.55	.78
Na_2O	4.44	3.49	3.78	3.11	4.36	3.81	4.99	4.33	4.44	5.27	4.26	3.93	2.89	3.31	3.68
K_2O	1.08	1.27	1.10	1.06	2.22	3.06	4.19	4.63	5.31	5.04	4.74	5.78	5.26	5.92	4.78
TiO_2	.....	.....	.45	2.88	1.59	.19	.....	.....	.....	.....	.30	.....	.....	.41	.....
P_2O_5	.....	.01	.08	.34	.58	.88	.....	.....	.....	.....	.....	.....	.....	.....	.....
MnO	.....	.10	.11	.22	.....	.35	.09	.....	.....	.....	.....	.....	.....	.....	.....
S	.....	.....	.....	.13	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
H_2O+	.72	.72	.82	.46	.32	.48	.39	.57	.31	.30	.52	.59	.51	.48	.31
H_2O-			.18	.15	.14	.09			.17				.05		.10

in the basic syenite (monzodiorite) liquid, but would in that of the augite syenite magma.

As a result of partial crystallization, of gravity sorting of the different crystals, and of a slight rise of bytownite and labradorite in the early stages, there is thus produced a zone in the upper part of the magma chamber rich in plagioclase crystals. Before the stage is reached at which plagioclase starts to sink, the feldspar crystals might thus form at least 35 per cent of the mass, and may well constitute as much as 50 per cent or more, allowance being made for the removal of the mafic minerals. Under stress such a magma could be made to flow. It is this upper stratum of crystal mush that the writer postulates is forced upward to higher levels and intruded into the Grenville beds in huge laccolithic or lens-like forms. Such a magma may readily brecciate the Grenville formations, include blocks of them, and send a few dikes into the surrounding country rock. Vola-

TABLE III

NORMS OF AVERAGE CHEMICAL ANALYSES OF ADIRONDACK IGNEOUS ROCK TYPES

	Pc	Quartz	Or	Ab	An	Di	Hy	Ol	Mt	Il
1.....	$Ab_{29}An_{71}$	1.38	6.67	37.73	48.93	1.97	1.26	.....	1.39	.....
2.....	$Ab_{25}An_{75}$	.....	7.78	29.34	46.14	2.81	8.24	1.89	2.32	.....
3.....	$Ab_{29}An_{71}$	2.58	6.67	31.96	42.26	7.69	5.48	.....	1.86	.91
4.....	$Ab_{35}An_{65}$	.....	6.12	26.20	25.58	13.05	.70	17.48	3.94	5.47
5.....	$Ab_{47}An_{53}$	.....	13.10	36.70	21.8	10.6	1.1	3.8	8.1	2.9
6.....	$Ab_{45}An_{55}$	2.86	18.13	32.17	21.43	3.05	12.50	.....	6.57	.36
7.....	$Ab_{61}An_{39}$	1.8	24.46	42.44	14.18	7.24	2.90	.....	5.8	.....
8.....	$Ab_{60}An_{40}$	9.33	27.38	36.70	12.77	2.93	6.18	.....	3.5	.....
9.....	$Ab_{70}An_{30}$	9.0	31.30	37.50	8.7	5.0	3.8	.....	3.7	.....
10.....	$Ab_{77}An_{23}$	10.50	30.10	44.50	7.2	3.6	.....	.....	3.70	.....
11.....	$Ab_{72}An_{28}$	18.0	27.80	36.16	7.51	3.07	3.38	.....	2.78	.93
12.....	$Ab_{76}An_{24}$	16.28	34.11	33.22	7.35	2.82	3.77	.....	1.86	.....
13.....	$Ab_{54}An_{46}$	22.68	31.14	24.65	11.12	.....	6.78	.....	2.32	.....
14.....	$Ab_{74}An_{26}$	23.91	35.18	28.03	5.71	1.31	1.31	.....	2.12	.76
15.....	$Ab_{83}An_{17}$	35.8	28.30	29.40	3.2	0.5	0.6	.....	1.39	.....

1. Anorthosite (Marcy type), *N.Y. State Mus. Bull. 138*, p. 32, average of analyses Nos. 2 and 3.
2. Anorthosite, Carnes Quarry, Altona, Clinton Co., *N.Y. State Mus. Bull. 138*, p. 32, analysis No. 5.
3. Pyroxenitic anorthosite (Whiteface type), *N.Y. State Mus. Bull. 138*, p. 36, average of analyses Nos. 1, 2, and 3.
4. Gabbro, average of 7 analyses, *N.Y. State Mus. Bull. 170*, p. 34.
5. Augite–hypersthene syenite, 1 mile south of Tinney Corners, Lake Bonaparte Quadrangle, *N.Y. State Mus. Bull. 269*, p. 32.
6. Basic syenite (Augite–hypersthene syenite), from near Raquette Falls, *N.Y. State Mus. Bull. 115*, p. 514, analysis No. 1.
7. Augite syenite, average of 3 analyses, *N.Y. State Mus. Bull. 269*, p. 33, analysis No. 2; p. 35, analysis No. 4; and *Bull. 115*, p. 514, analysis No. 3.
8. Quartzose augite syenite, average of 4 analyses, *N.Y. State Mus. Bull. 115*, p. 514, analyses Nos. 4 and 5; and *Bull. 269*, p. 35, analyses Nos. 5 and 6.
9. Quartzose hornblende syenite, average of 2 analyses, *N.Y. State Mus. Bull. 115*, p. 521; and *Bull. 269*, p. 37, No. 8.
10. Quartz augite syenite, *N.Y. State Mus. Bull. 269*, p. 35, No. 7.
11. Hornblende granosyenite, average of 3 analyses, *N.Y. State Mus. Bull. 153*, p. 15; *Bull. 269*, p. 38, No. 9, and p. 41, No. 10.
12. Augitic hornblende quartz syenite, average of 2 analyses, *N.Y. State Mus. Bull. 115*, p. 514, Nos. 7 and 8.
13. Labradorite-bearing border facies of anorthosite, average of 2 unpublished analyses by R. B. Ellestad for Robert Balk.
14. Hornblende–biotite granosyenite, average of 4 analyses, *N.Y. State Mus. Bull. 269*, p. 41, Nos. 11 and 12; *Bull. 153*, p. 19; and one unpublished analysis.
15. Biotite granite, average of 2 analyses, *N.Y. State Mus. Bull. 115*, p. 511; and *Bull. 269*, p. 43, No. 13.

tiles contained in the liquid part are available for contact metamorphism. During the process of intrusion there would be local clotting and jamming together of the crystals, due to differential flowage of the various threads of the magmatic currents and to a tendency for local faster movement of the liquid than of the crystals where the stresses are small. These features would result in local rigid anorthositic masses even before any further crystallization took place.

During and after the emplacement of the magma, crystallization of the residual solution continues. If we assume the intruded magma to have had 45 per cent of plagioclase crystals and the residual liquid to be that of a basic syenite, and permit 20 per cent more of the total volume to crystallize, then about 15 per cent more crystalline plagioclase and 5 per cent mafic minerals will be added, giving a total of 65 per cent crystalline material. By or before the time the magma has reached this degree of crystallization, stress will tend to squeeze out the residual liquid, and the resultant aggregate will consist of 92 per cent plagioclase and 8 per cent mafic minerals. Some allowance must be made for mafic minerals carried up with the plagioclase and for the crystallization of residual films of interstitial liquid; but a mass consisting of 90 per cent labradorite and 10 per cent mafic minerals may thus be obtained. The grains of plagioclase show granulation on the borders due to crushing, indicating that stresses were very strong and sufficiently effective to squeeze out residual liquid. Facies still higher in plagioclase may have resulted from magma richer in solid plagioclase at the time of intrusion and a smaller percentage of subsequent crystallized material before deforming forces squeezed out the residual liquid. Clotting of the plagioclase crystals during intrusion and deformation, and further gravity sorting at the site of emplacement, may also result in large masses very low in mafic minerals. The more mafic facies of the anorthosite are readily accounted for either by a greater percentage of crystallization in place, as at the border through more rapid chilling, or through a less efficient squeezing out of the residual liquid during deformation.

It will be noted that the results are not dependent upon the exact figures chosen for an example. If it is thought that a mass with 45 per cent crystalline plagioclase would have too low a plasticity to

show the necessary intrusion phenomena, then a mass with the requisite smaller percentage (say 30 per cent) of solids may be chosen. In this case the mass would acquire the necessary physical character for differentiation by deformation at an earlier period of crystallization (perhaps 55 per cent solid). On the other hand, the higher the plagioclase content at the time of intrusion, the less the necessary amount of subsequent crystallization and the smaller the percentage of ferromagnesian minerals that will result. All that it is necessary to assume is a narrow range (say 25 per cent) within which there is a change from a mass with sufficient mobility to be intruded as a whole to one with appropriate characters to permit differential movement of liquid and crystals under stress.

The norm ratio of albite to anorthite in the analyzed Marcy and Whiteface anorthosites averages $Ab_{29}An_{71}$. The plagioclase in equilibrium conditions with this, based on experimental data, is about $Ab_{70}An_{30}$, or the norm ratio of the feldspar in the granosyenites of the Adirondacks. The plagioclase of the anorthosite, however, in part, varies from bytownite to oligoclase, predominantly labradorite, and the composition of the modal[1] plagioclase of the analyzed specimens of Marcy anorthosite is approximated by Kemp as varying from $Ab_{30}An_{70}$ to $Ab_{25}An_{75}$, and of the anorthositic gabbro from $Ab_{34}An_{66}$ to $Ab_{28}An_{72}$. Hornblende is found locally in small amounts in the anorthosites and, together with the oligoclase, may represent residual crystallization. A little interstitial orthoclase, quartz, and oligoclase may also be present. It has already been shown that liquid corresponding in composition to basic syenite and syenite may be derived by fractional crystallization of labradorite and mafic minerals from an average basalt. All the data are consistent with the assumption that the interstitial liquid squeezed out from the anorthositic lens may have varied from basic syenite at early stages to granosyenite at the last. It would seem probable, however, that some of the liquid squeezed out from the present exposed anorthosite masses would have been intruded at higher levels and have since been eroded.

[1] T. F. W. Barth (*Am. Min.* [1930], pp. 129–43) gives the mode of the anorthositic plagioclase of the Adirondacks as about $Ab_{30}An_{70}$.

Balk,[1] from a study of the structural relations in the field, arrived at the conclusion that the parent magma was probably a gabbroid syenite with labradorite phenocrysts of a type such as he found along the eastern margin of the anorthosite. It will be noted that theoretical physico-chemical considerations have led the writer independently to a similar conclusion. Dr. Balk has permitted the writer to quote

TABLE IV

CHEMICAL ANALYSIS OF GABBROID LABRADORITE-BEARING SYENITE

SiO_2	51.72
Al_2O_3	17.07
Fe_2O_3	3.01
FeO	12.64
MgO	2.54
CaO	6.72
Na_2O	2.66
K_2O	2.80
H_2O+	.23
H_2O-	.04
CO_2	.18
	99.61

Location.—Quarry 1,200 feet south of the bridge of the main highway across Schroon River, northwest of Holiday Pond, Elizabethtown Quadrangle, New York.

an unpublished analysis of such a type (see Table IV), made for him by R. B. Ellestad in the laboratory of Professor Grout.

There are, no doubt, other factors that enter into the formation of anorthosite, but those here discussed appear adequate to explain the major features of the problem in hand.

COMPARISON OF ADIRONDACK STEM WITH OTHER COMAGMATIC SERIES

Much may be learned of the origin of the Adirondack syenitic rocks through a comparison with rock series of other regions. The

[1] *Op. cit.*, pp. 301–2.

curves for variation of the major oxides with silica have been plotted and compared for the Coast Range–Sierra Nevada,[1] Adirondack, Bergen-Jotun,[2] Saganaga-Vermillion,[3] and for the average normal volcanics (basalt, andesite, dacite, rhyolite) as computed by Daly.[4] The curves for the Adirondack and average volcanic series are shown in Figures 1 and 2, with the limitation that H_2O, TiO_2, and P_2O_5, are not plotted, and the analyses have not been recalculated to 100 per cent. Analyses 4–15, with the exception of 13, are plotted in Figure 2. The analysis of the labradorite-bearing granosyenite (13) varies widely from the curve of variation, for it is a mixed rock and does not belong to a true line of liquid descent.

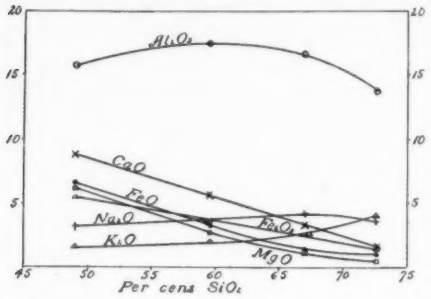


FIG. 1.—Variation diagram for average basalt, andesite, dacite, and rhyolite. After Bowen.

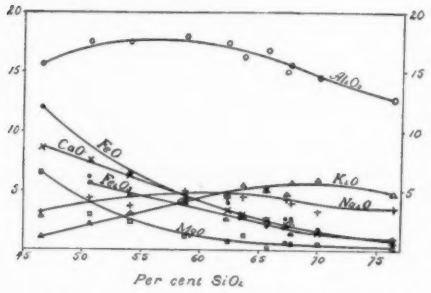


FIG. 2.—Variation diagram for the Adirondack series.

In Table V six different rock series are compared on the basis of

[1] Buddington, "Coast Range Intrusives of Southeastern Alaska," *Jour. Geol.*, Vol. XXXV (1927), pp. 224–46; C. H. Clapp, "Sooke and Duncan Map Areas," *Geol. Surv. Can. Mem. 96* (1910).

[2] Goldschmidt, "Geologische-petrographische Studien in Hochgebirge des südlichen Norwegens," *op. cit.* (1916), No. 2; "Stammestypen der Eruptivgesteine," *op. cit.* (1922), No. 10.

[3] Grout, "The Saganaga Batholith of Minnesota-Ontario," *Jour. Geol.*, Vol. XXXVII (1929), pp. 562–91, analysis 7 omitted; and "The Vermillion Batholith of Minnesota," *Jour. Geol.*, Vol. XXXIII (1925), pp. 467–87, analyses 16, 9, 13, 14, and 17 omitted.

[4] Bowen, *op. cit.*, and pp. 122–24.

TABLE V

COMPARISON OF ROCK SERIES OR STEMS BASED ON EQUIVALENCE OF PLAGIOCLASE

	1	2	3	4	5	6
	Trondhjem, Norway (After Goldschmidt)	Coast Range, Alaska (After Buddington)	St. Urbain, Quebec (After Mawdsley)	Adirondacks, New York Buddington	Bergen-Jotun, Norway (After Goldschmidt)	Christiania, Norway (After Brögger)
Albite....					Aegerine Granite	Biotite and Rapakivi Granites
	Trondhjemite	Biotite, Granite, and Albite Quartz Diorite		Biotite, Granite (Quartz Monzonite)	Diopside Granite	Soda granite (Hornblende, Arfvedsonite, Aegerine Granite)
Oligoclase...	Trondhjemite (Biotite Quartz Diorite)	Biotite, Quartz, Monzonite	Hypersthene–Hornblende Granite (Quartz Monzonite and Granodiorite)	Hornblende and Hornblende–Biotite Granosyenite (Quartz Monzonite) and Granite	Diopside or Hypersthene Granite	Quartz Nordmarkite and Nordmarkite
	Opdalite (Biotite–Pyroxene Quartz Diorite)	Hornblende-Biotite, Quartz Monzonite	Hypersthene Quartz Diorite	Augite or Hornblende Syenite (Quartz Monzonite and Monzonite)	Diopside–Hypersthene Syenite and Pyroxene Mangerite	Nordmarkite, Akerite, Laurvikite
Andesine....	Biotite–Pyroxene Diorite	Hornblende–Biotite, Granodiorite, and Quartz Diorite, and Hornblende Diorite	Hypersthene Quartz Diorite, Hypersthene Diorite, and Anorthosite	Augite–Hypersthene Syenite (Monzodiorite)	Augite–Hypersthene Mangerite, Jotun-Norite	Laurvikite
Labradorite.....	Biotite Norite	Gabbro and Norite	Anorthosite	Gabbro, Norite, Anorthosite	Gabbro, Norite, Anorthosite	Essexite or Gabbro

NOTE.—The rock names in parentheses, except for column 6, are according to the classification of Johannsen.

equivalent plagioclase. The data for the Trondhjem series are from Goldschmidt,[1] and for St. Urbain from Mawdsley.[2]

In comparison with both the average plutonics and the average volcanics, K_2O and Na_2O plotted against silica are higher in the Adirondack series, but K_2O exceeds the average to a much greater degree than does Na_2O throughout the intermediate ranges. The ration of FeO to MgO is much higher than the average, and CaO is much lower. The high K_2O is indicative of the syenitic aspect of the series.

It has been shown in a discussion of the anorthosite that a basic syenite like that of the Adirondacks may be derived from an average basaltic magma through the crystallization of about half the magma as an aggregate of plagioclase (like that now found in the anorthosites) and of diopside and a little hypersthene, olivine, and magnetite. The sinking of these minerals would give rise to low lime and magnesia in the resulting liquid, and thus indirectly result in the high ratio of FeO to MgO. The rise of the Al_2O_3 curve to a maximum, such as is shown by the Adirondack series, has been attributed by Bowen[3] in a number of cases to a relatively high degree of reaction between the separated plagioclase crystals and the liquid in the early stages of crystallization and cooling. He also suggests[4] that the change from a rising to a falling slope may be due to the appearance of hornblende, where this mineral plays a part in the differentiation. In the case of the Adirondack series there would be adequate opportunity for reaction of the plagioclase with the liquid in the early stages of crystallization, for it is postulated as having taken place in a large, deep-seated mass where the crystals at first rose slightly, and finally may have remained stationary. Hornblende similarly appears as a constituent of the rocks at about the same silica percentage at which the Al_2O_3 starts to decline. In the Coast Range series, hornblende starts at a much smaller silica percentage (Table VI), and the Al_2O_3 curve accordingly shows a decline throughout its course.

In the Adirondack series a curve for K_2O plotted against SiO_2 is much higher than that of the similar curve for the generalized volcanics, except at each extreme of composition. But if the normative

[1] *Op. cit.*

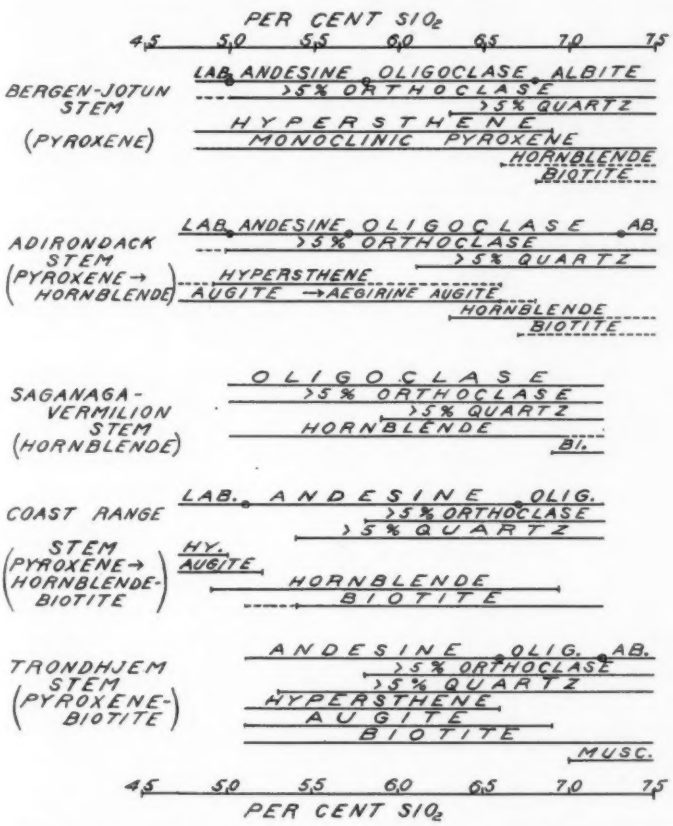
[2] J. B. Mawdsley, "St. Urbain Area, Quebec," *Can. Geol. Surv. Mem. 152* (1927).

[3] *Op. cit.*, pp. 111–12. [4] *Op. cit.*, p. 113.

percentage of orthoclase (or the percentage of K_2O) is plotted against the normative percentage of albite in the plagioclase, it is found that

TABLE VI

MINERAL VARIATION OF TYPICAL STEMS



NOTE.—Dashed line indicates minor or local constituent. Oligoclase also extends to 75 per cent SiO_2 in both Adirondack and Trondhjem lines of descent.

the percentage of orthoclase is only slightly greater in the Adirondack series than in the average type. This would indicate that the relatively high K_2O curve of the Adirondack series, when plotted

against SiO_2, may be due only in part to the early precipitation of orthoclase, but in part may result from the prolonged delay in the precipitation of quartz. The Adirondack series has a much higher percentage of ferromagnesian minerals than the average volcanic series, when compared on the basis of similar normative plagioclase, and a slightly smaller percentage when compared on the basis of similar SiO_2, except when the SiO_2 is greater than 62 per cent.

When plotted against the normative ratio of albite in the plagioclase, the Adirondack series has a percentage of orthoclase similar to that of the Coast Range series; but when plotted against the silica percentage, the Adirondack rocks show a higher K_2O than the Coast Range stem. The Adirondack series is also much higher in ferromagnesian minerals than the Coast Range rocks, when similar normative plagioclase composition is considered. The Bergen-Jotun series is similar to the Adirondack suite. These facts all serve to indicate that the relatively high percentage of K_2O for the Adirondack suite when plotted against SiO_2 is primarily, in large part, the result of prolonged delay in the formation and precipitation of quartz, and perhaps, to a minor extent, of the higher percentage of ferromagnesian minerals and early precipitation of orthoclase. In the Adirondack rocks zircon is much more abundant as an accessory mineral than in the Coast Range sequence, and titanite is a much more abundant accessory mineral in the Coast Range–Sierra Nevada rocks than in the Adirondack series.

Grout[1] has described a series of rocks in which the variation is from hornblende shonkinite with about 50 per cent SiO_2, through syenite, to granite. Hornblende is the predominant ferromagnesian mineral throughout, except in the siliceous granites, and oligoclase is the plagioclase throughout. Quartz starts at a lower silica percentage than in the Adirondack series. The variation curves for Na_2O, K_2O, MgO, and FeO are very similar to those of the average volcanics; Al_2O_3 is also very similar, except that the maximum for Al_2O_3 lies at a higher SiO_2 percentage. CaO is higher throughout, except at the high silica end; and Fe_2O_3 is much lower, except at the basic and acid extremes. The curves for the Minnesota series are wholly dis-

[1] "The Saganaga Batholith of Minnesota-Ontario," *Jour. Geol.*, Vol. XXXVII (1929), pp. 562–91; and "The Vermillion Batholith of Minnesota," *Jour. Geol.*, Vol. XXXIII (1925), pp. 467–87.

similar from those of the Adirondack rocks, but similar to the Coast Range–Sierra Nevada series except for the Al_2O_3 curves and for K_2O at silica percentages between 60 and 72, in which K_2O is lower in the Minnesota rocks. Biotite in the Cordilleran rocks, instead of wholly hornblende, accounts for this difference.

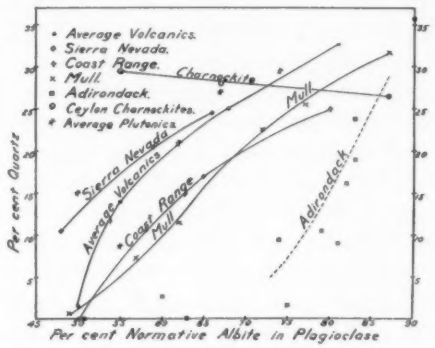


FIG. 3.—Variation diagram for quartz with normative plagioclase in weight per cent

Average volcanics.—Average analysis No. 55, diabase; No. 46, andesite; No. 42, dacite; and No. 7, rhyolite. If average basalt No. 53 is used, the curve will cross the zero line at about 52 per cent Ab. R. A. Daly, *Igneous Rocks and Their Origin*, McGraw Hill, 1914.

Sierra Nevada.—Analyses 1, 3, and 5, A. F. Buddington, "Cost Range Intrusives of Southeastern Alaska," *Jour. Geol.*, Vol. XXXV (1927), p. 245.

Coast Range.—Analyses pp. 204, 211, 216, and 221, Buddington and Chapin," Geology and Mineral Deposits of Southeastern Alaska," *U.S. Geol. Survey Bull. 800.*

Mull.—Average of analyses I and III, p. 17; IV, V, VI, VII, VIII, and IX, p. 17; analysis I, p. 19; average of IV and V, p. 19; analysis VI, p. 19; and average of I, II, and III, p. 20; E. B. Bailey and others, "Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban," *Mem. Geol. Survey Scotland*, 1924.

Adirondacks.—Analyses p. 7, 4–15 inclusive, with exception of 13.

Ceylon charnockites.—Average of I.B, I.G, I.H, and II.B; I.F, I.J, and I.I; and I.C and I.D, F. D. Adams, "Geology of Ceylon," *Can. Jour. Research*, Vol. I (1929), p. 483.

Average plutonics.—Average analyses No. 43, quartz diorite; 45, diorite; 4, granite; 1, Pre-Cambrian granites; 41, granodiorite, R. A. Daly, *Igneous Rocks and Their Origin*, McGraw Hill, 1914.

In the Coast Range–Sierra Nevada, Trondhjem, Mull, and average volcanics, normative quartz in general is 5 per cent or greater before the normative plagioclase is as albitic as $Ab_{45}An_{55}$ (Fig. 3); whereas in the Adirondack stem, quartz does not exceed 5 per cent

until the plagioclase has a norm ratio of about $Ab_{60-65}An_{35-40}$; and in the Bergen-Jotun and Christiania series, quartz in general exceeds 5 per cent only when the plagioclase has a norm ratio of about $Ab_{75}An_{25}$, or a greater percentage of the albite molecule.

The Adirondack suite of rocks, then, when compared with the average volcanics and the Coast Range–Sierra Nevada rocks on the basis of similar normative plagioclase and similar percentages of orthoclase and ferromagnesian minerals, is low in silica. The generalized volcanic series has been characterized by Bowen as a hornblendic sequence, and the Coast Range–Sierra Nevada stem is of similar character. The differentiation of the Adirondack stem, on the other hand, appears to have been given its peculiar characteristics by the prolonged separation of monoclinic pyroxene (Table VI). Diopsidic pyroxene or hypersthene-augite has a higher silica percentage (about 50 per cent) than the usual magmatic hornblende (38 to 45 per cent) of gabbroic and dioritic rocks, and its separation would therefore result in relatively low silica rocks, such as characterize the Adirondack sequence except at the granitic end, where it, too, is characterized by the separation of hornblende.

From the standpoint of lines of descent through fractional crystallization, the Bergen-Jotun series is characterized by the separation of pyroxene, the Saganaga-Vermillion by hornblende, the Coast Range–Sierra Nevada by a pyroxene-hornblende-biotite succession with overlapping, and the Trondhjem by pyroxene-biotite (Table VI).

Soda granite[1] of trondhjemite character also occurs in association with the Coast Range series where its peculiar character has been ascribed to the activity of volatiles. Vogt[2] has suggested that trondhjemite in the Sulitelma region has been formed as a late member of an intrusive series as a result of the formation and separation of highly potassic molecules in the mica minerals, and Bowen[3] follows Schaller in suggesting that probably all albite-rich rocks are formed

[1] Buddington, *op. cit.*, p. 242; and H. T. James, "Britannia Beach Map Area, B.C.," *Geol. Surv. Can. Mem. 158* (1929), pp. 50, 57–59.

[2] Thorolf Vogt, "Sulitelmafeltets geologi og petrografi," *Norges Geologiscke undersoekelse 121* (1927), p. 496.

[3] *Op. cit.*, p. 132.

by a process of replacement. All these proposals have one concept in common, namely, the essential activity of volatiles or water-rich solutions. The only rocks with high soda ratio so far described from the Adirondacks occur in association with the magnetite ores at Mineville.

In the Christiania, Bergen-Jotun, and Adirondack series, the youngest dikes are diabase, in part carrying olivine; whereas in the Coast Range Series the lamprophyre dikes are largely spessartite with much brown hornblende. Locally, also, facies of the Coast Range magma have crystallized as hornblendite, all suggesting a difference in the volatile content.

It is usually considered that one of the major factors in determining the formation of hornblende rather than pyroxene is the relative percentage of volatiles[1] in different magmas. This is the hypothesis adopted by Goldschmidt[2] to explain the difference between the pyroxene-biotite (Trondhjem) stem and the pyroxene (Bergen-Jotun) stem of Norway. He describes the Trondhjem series of rocks as intruded in shales with a relatively high water content. Biotite appears in all rocks of this series varying from norite to granite, and in the granitic members even muscovite appears. The Bergen-Jotun rocks he described as intruded into older granite or water-poor gneiss. Pyroxene, practically without hornblende or biotite, characterizes this series from end to end. The rocks vary from a type called Jotun-norite or basic syenite, through mangerite or syenite, to pyroxene granite. Goldschmidt interprets the rocks of the Trondhjem stem as formed from wet magmas, and of the Bergen-Jotun stem as formed from dry magmas. Biotite and amphibole granites do appear in the Bergen-Jotun region, but they are not considered by Goldschmidt to be in the direct line of differentiation of the Bergen-Jotun stem.

The writer would similarly explain the basic and a part of the intermediate rocks of the Adirondack stem as resulting from differentiation of a relatively dry magma characterized by the separation of pyroxene, and a part of the intermediate and the granitic rocks of the stem as resulting from differentiation of a wetter magma charac-

[1] S. S. Shand, *Eruptive Rocks* (London: Thomas Murby & Co., 1927), pp. 120–21.

[2] "Stammestypen der Eruptivgesteine," *op. cit.*, p. 9.

terized by the separation of hornblende. The Adirondack stem would thus lie between the Coast Range–Sierra Nevada type and the Bergen-Jotun type, but much closer to the Bergen-Jotun stem. The Adirondack rocks are interpreted as differentiated in a deep-seated chamber where little water could be obtained from the enclosing rock, if such a considerable accession of water is considered a possibility. One might also postulate that the original primary magma might vary widely in its content of volatiles.

Within a great belt in the northwest Adirondacks, Grenville formations are the predominant rocks, and associated with them is a dioritic series of intrusives older than the syenitic group. The dioritic suite (Rossie series) varies from gabbro, through biotite-pyroxene diorite, biotite-hornblende-pyroxene quartz diorite, to biotite-oligoclase quartz diorite with a little muscovite. This sequence strongly resembles the Trondhjem series. It is not clear why pyroxene should be stable together with biotite to so late a stage of differentiation in association with a relatively high volatile content, but such seems to be indicated.

Within this same belt, dominated by Grenville beds, there are outlying sheets and stocks of members of the syenitic series. These differ from those of the main Adirondack core in that hornblende and biotite are more common in the larger masses at earlier stages of differentiation, and thereby suggest formation from a series of magmas with a relatively high water content. This would appear to be in line with Goldschmidt's suggestion of accession of water from sediments. The writer would point out, however, that it may also be interpreted by the hypothesis that only the more fluid (because of higher water content) facies of the syenitic magmas were able to be forced freely far into the Grenville sediments, analagous to the fact that many of the smaller offshooting dikes and lenses within this same belt are the most quartzose and pegmatitic facies and are accompanied by phenomena indicating a higher content of volatiles. Similar phenomena are found in the case of the Coast Range intrusives where early members of the magmatic sequence dominate among the outlying smaller masses of intrusives, but are accompanied by facies indicating a high volatile content, such as hornblendites, pegmatite, albitic rocks, etc.

The charnockite series of rocks, to which the St. Urbain suite is very similar, present the phenomena that (1) hypersthene occurs in all members of the series from pyroxenite and norite to the most siliceous granite, and (2) that normative quartz[1] appears very early and may form as much as 30 per cent of the rock when the normative plagioclase is no more sodic than $Ab_{42}An_{58}$.

By comparison with the Sierra Nevada granodiorites containing hornblende and biotite, the Ceylon hypersthene charnockites are low in alumina, high in TiO_2, and especially high in FeO. But these differences alone do not seem sufficient to wholly account for the pronounced difference in the mineral composition, particularly as the percentage of K_2O is similar.

A hypothesis, consistent with a relatively dry differentiation, would be that due to some set of physico-chemical conditions, which cannot be specified,[2] the original magma which yielded the charnockite series started to crystallize as an aggregate of pyrope garnet (with some grossularite in solid solution), jadeite-bearing diopside, olivine, enstatite, bytownite, etc. Jadeite, grossularite, and olivine are all low silicate minerals. The ratio of Na_2O to SiO_2 is 1 to 2 in jadeite as compared with 1 to 6 in albite, the ratio of CaO to SiO_2 in garnet is 1 to 1 as compared to 1 to 2 in anorthite, and the ratio of MgO to SiO_2 in olivine is 2 to 1 as compared with 1 to 1 in diopside, pyrope, or hypersthene. The separation of such compounds from the average basaltic magma would leave it with considerable excess silica, which would appear as quartz in later members of the series. Eskola[3] has strongly emphasized the genetic association of olivine rock, eclogite, and labradorite rock in certain regions of Norway. He finds that the olivine rocks and eclogite are older than the anorthosite, and that the major minerals of the eclogite are diopside (jadeite-bearing), garnet (pyrope), olivine, and enstatite. The pyrope contains a variable amount of the grossularite molecule. A pyrope garnet also occurs in the anorthosites near Bergen.

[1] F. D. Adams, "The Geology of Ceylon," *Can. Jour. of Research*, Vol. I (1929), p. 483.

[2] Eskola follows Fermor in suggesting that high pressure is the predominant factor.

[3] Pentti Eskola, "On the Eclogites of Norway," *Kristiania Videns. Skr. I, Mat.-Naturv. Kl.*, No. 8 (1921), pp. 66–70.

In the Christiania series of rocks, the nepheline molecule appears in the norm calculations of many of the quartz-free members, whereas this is not the case in either the Adirondack or Bergen-Jotun stems. A complex series of alkalic dike rocks is reported to be genetically associated with the Christiania stem, while none of this series has been found in the Adirondack or Bergen-Jotun regions. The feldspars of the Coast Range rock types are crystallized to a far greater degree as separate grains of plagioclase and potassic feldspar than are the Adirondack rocks where the feldspar is predominantly microperthite, though microperthite is also prominent in the Coast Range kindred. In the Christiania series, the plagioclase and orthoclase molecules are crystallized as anorthoclase in the laurvikite and laurdalite, and as microperthite in the more siliceous facies. Quartz does not appear in general in the Christiania sequence in amounts greater than 5 per cent until the plagioclase is more albitic than that of any of the other stems referred to. In the Christiania rocks sodic pyroxenes are common in rocks as siliceous as granite. The Adirondack rocks, except for the basic and granite extremes, are higher than normal in soda, but they are relatively still higher in potash for similar silica percentages.

The Christiania and Adirondack stems thus have certain features in common, and to this extent Alling's proposal to call the appropriate Adirondack rock types laurvikite, nordmarkite, and quartz nordmarkite is justified; but there are also certain marked differences, and the writer feels that the reasons for adopting this nomenclature are not compelling at the present time.

Grout[1] has discussed the trend of differentiation in forty cases of rock series by plotting alkalis against deficiency and excess of silica in the norms. The writer's deductions are in conformity with Grout's conclusions.

In conclusion, it is recognized that the deductions drawn are subject to criticism in that the fundamental data consist in part of norms instead of modes, and of averages of similar rock types having their origin, perhaps, from different magmatic reservoirs instead of individual types forming representatives of a single connected series,

[1] "Graphic Study of Igneous Rock Series," *Geol. Soc. Amer.*, Vol. XXXIII (1929), No. 3, pp. 617–38.

and that there has unquestionably been some differential movement of the different minerals crystallizing from the magma. It is believed, however, that the probable magnitude of the error thus involved would not invalidate the general conclusions and that certain definite trends are indicated.

The writer is indebted to N. L. Bowen, D. H. Newland, and C. H. Smyth, Jr., each of whom read the manuscript and contributed pertinent comments, and to Robert Balk for permission to use certain unpublished analyses and for the opportunity to read previous to publication the manuscript of a most detailed report on the structural phenomena of the igneous rocks of the eastern Adirondacks and their significance.

THE ISOSTASY OF THE UINTA MOUNTAINS

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ABSTRACT

The main uplift of the Uinta Mountains is a broad, simple, anticlinal arch which attained a mean altitude of 1.82 miles in early Tertiary time, as a result of an orogenic upthrust of 0.66 miles added to a general epeirogenic uplift of the region of 1.16 miles. The culminating point of the arch was of course higher than the mean altitude, but probably never exceeded 2.8 miles. The upthrust of 0.66 miles necessitated a downthrust of the sial into the sima of 5.94 miles to maintain isostatic equilibrium. Under erosion the mountain column lost load and rose by flotation, a volume of sima in depth replacing that of the sial removed in the inverse ratio of their specific gravities; so that the total column down to the zone of compensation always maintained a constant mass. Immediately anterior to the elevatory movement the top of the Point of Rocks formation was about at sea level; so that the difference between the position of this datum plane, as restored by Powell in his displacement diagrams, and the present surface is the measure of the prism removed by erosion. This is the equivalent of a prism having a uniform thickness of 4.42 miles. During this removal the mountain column rose 3.98 miles, and the loss of height of the range was 0.44 miles. The residual mountains of today are the equivalent of a prism having a uniform thickness of 0.22 miles. The rise separated the range from the plateau on the north by an upthrow of 3.98 miles on the north-flank fault. In addition to this there was a downthrow of the plateau on the same fault of 0.6 miles due to the load of Tertiary. On the south flank of the main uplift the corresponding upthrow was by flexure of the stratified rocks near the surface, but probably by a fault in depth. The mountains of the adjoining Yampa Plateau uplift were much lower originally than the main uplift and, as features of the relief distinct from the epeirogenic uplift, have been completely wiped out by erosion. The effect of elastic expansion due to relief of load is not considered in the discussion, which is intended to illuminate the behavior of mountains under the control of isostasy rather than to arrive at precise numerical results. For purposes of comparison the isostatic relations of the Black Hills are briefly reviewed.

GENERAL CONSIDERATIONS

When an elongated prism of the sial collapses to make a mountain range, by reason of compressive elastic stress in excess of the strength of the rocks in that prism, then there is a concentration of mass in the zone of failure. If, notwithstanding its failure, the crust is still strong enough, this concentration of mass will constitute a superimposed burden to be supported as long as the mountains endure. In this event a young mountain range, standing high above the normal continental platform, would reveal large anomalies in the measured values for the force of gravity at any point on its surface. The crustal column culminating in such a range would not be in isostatic balance with neighboring columns unaffected by the collapse. But the values for the force of gravity obtained in several

mountainous regions show very small anomalies, and there is good reason for the belief that they actually are in isostatic balance. If this is true, it is most probable that the balance is effected by flotation. That is to say, at the time of the collapse and upthrust to form the mountains there was a much larger downthrust of the sial into the sima. If we suppose the sial to be a layer 20 km. thick, measured from sea level, having a mean specific gravity of 2.7, resting upon a layer of sima 20 km. thick, with a mean specific gravity of 3, down to the zone of compensation, then for every 1 mile of upthrust, there will be 9 miles of downthrust as appears from the equation: $2.7\ (1+x)=3x$ and $x=9$; where x is the amount of downthrust. The sima displaced by the downthrust is equal in mass to that added to the mountain zone by the collapse of the sial; and it is disposed of by plastic rock flow into an attenuated layer extending far on either side of the region of disturbance. This attenuated layer, although a load added to a limited region of the earth's crust is compensated by a general adjustment of the spheroid as a whole; and it may be said to vanish as a separate entity into the general mass of the earth. The excess mass having thus conveniently disappeared, we have remaining a column of folded, broken, crushed, and foliated or flowed sial, floating in the sima, the top of which we recognize as a mountain range. The weight of the normal column of the earth's crust in neighboring regions of no disturbance, down to our assumed depth of compensation, is $20\times2.7+20\times3=114$; and this is precisely the weight of the mountain column. For, let x be the amount of upthrust in the zone of collapse, then its weight is:

$$2.7(x+20+9x)+3(20-9x)$$

or

$$54+27x+60-27x=114.$$

It is immaterial what depth we assume for the zone of compensation, the equality of mass remains unaffected.

But the upthrust of the mountain range inaugurates vigorous erosion, and this in the course of time involves an important loss of load, since the products of erosion are carried by the streams to other regions. But at all stages of the degradation of range the mass of the column from the surface down to the zone compensation remains

constant, and is expressed by the quantity 114. For as load is removed from the top of the column the latter rises by flotation, and the heavier sima replaces it at the bottom. Let x be the amount of upthrust of the range and y the loss of height due to erosion at any stage of its degradation. Then at that stage $x-y$ is the height of the range considered as a uniformly high prism. The mass of the column at any stage is thus:

$$2.7[(x-y)+20+9(x-y)]+3\ [20-9(x-y)]$$

or

$$54+27(x-y)+60-27(x-y)=114.$$

While the column thus remains constant in mass, the floating part of it is steadily rising as it looses load by erosion at the top. The rise produces a shearing stress, and eventually a large fault or flexure, on the borders of the range. The relation between the amount of rise and the thickness of the effective prism removed is simple. Let 1 be the thickness of the prism removed and x the amount of rise induced by the removal. Then $3x=1\times 2.7$ and $x=0.9$. That is, for every mile removed from the top of the column, the rise of the latter is 0.9 mile and the loss of height of the range is only 0.1 mile. Thus, even if the flanking regions remain stable, the dislocation of the latter from the mountains will be 9 times the reduction of elevation of the effective flat-topped prism corresponding in volume to the range.

The rock inserted at the bottom of the rising column to compensate for the loss of load at its top is drawn from the sima of the adjacent regions on either side. Owing to the high viscosity of the material the stress difference which induces flow is most acute near the floating column and fades away at a distance. The compensating flow of sima comes, therefore, effectively from the immediate vicinity of the column and in approximately equal quantities from the two sides. The thickness of the layer thus withdrawn from the sima of the flanking regions will depend upon its lateral extent. Whatever this thickness may be, that of the layer inserted at the base of the floating column is 9 times the thickness of the prism removed by erosion; and the volume from each side will be 4.5 times that prism.

The mass withdrawn will, as a result of the high viscosity, have its maximum thickness at the side of the rising column and taper off to nothing away from it. The sima will doubtless find its way to the bottom of the column by curving or circuitous currents, controlled by the distribution of stress difference; but the effect, as regards redistribution of mass, will be as if a wedge-shaped prism had been withdrawn from the region on either side. The withdrawal of this effective wedge reduces the mass of the column beneath each flank and necessitates further compensation. This may be effected in two ways. In the first place the surface tends to sag, and the depression there created becomes a trap for detritus shed from the range in the course of its degradation. The load thus added at the surface tends to offset the loss of load in depth. But the detritus deposited in the depression, even when full of water, has a specific gravity probably not exceeding 2.4. The filling of the depression with an alluvial deposit of specific gravity 2.4 would only compensate four-fifths of the loss of load due to the loss of sima of specific gravity 3. If the deposit be thicker than the depth of the depression, as is true of many alluvial deposits along mountain flanks, there may be complete compensation. If it exceed five-fourths of the depth of the depression it will induce further sinking. Under continued depositional loading the floor of the depression will sink 4 for every 5 of added load. The sinking of the flanks will increase the throw of the bordering faults which dislocate the mountains from the lowlands.

If the region on either side of the rising column supplying sima to its base is narrow the depression at the surface will be acute; if it is wide, the depression will be shallow. The whole movement of transfer of heavy rock in depth and depression at the surface proceeds very slowly, since it is a direct consequence of the slow shift of load from the range by erosion; and while the different phases of that movement are referred to separately and in sequence, they really constitute a synchronous, complex process.

The second mode of compensating the reduction of mass in the flanking regions is by a general inflow of sima under small stress difference, requiring much longer time than where the stress difference is large near the base of the floating column.

POWELL'S DESCRIPTION OF THE UINTA MOUNTAINS

With these considerations in mind, and without apology for their dogmatic form of presentation, since the formulation of hypotheses is necessarily dogmatic, we may now endeavor to apply them to the Uinta Mountains as described by J. W. Powell.[1]

The Uinta Mountains in northeastern Utah are noteworthy for the simplicity of their general structural features. They constitute a range of outstanding individuality which attracted the attention of the early geological explorers of the Western United States. In Powell's monograph and particularly in the atlas which accompanies it we have a graphic account of its stratigraphy, structure, geological history, and geomorphic features. As an introduction to a consideration of the possible isostatic relations of the range I cannot do better than quote Powell's summary description of it:

> In the Uinta Mountains we have a great range carved from an anticlinal upheaval, the axis of which has an easterly and westerly trend, and is more than one hundred and fifty miles in length. . . . . Its axis has been lifted above the level of the sea about thirty thousand feet, and above the level of the adjacent country about twenty-five thousand feet. From flank to flank the flexure is about fifty miles, but varies much in width. We find on either flank, many miles from the axis, a line of maximum flexure, which line presents a subparallelism with the meandering axis. These lines have the effect of two monoclinal flexures in opposite directions, separated by the broad table, diversified by elevated valleys and peaks of which the great mass of the Uinta Mountains is composed. But the portion between these monoclinal flexures or lines of greatest flexure is itself gently flexed. In many places that which I have called the line of greatest flexure is indeed a fault, in one place on the north side of the Uinta Mountains having a throw of twenty thousand feet. On the south side the line of greatest flexure is very irregular, being complicated in some places by faults having uplifts opposed to the down throw of the flexure. On either side the great displacement is partly by faulting, partly by flexing, and either flank is a zone of diverse displacements where the strata are faulted, flexed, twisted and contorted in many ways.

Powell also estimated the volume of rock removed by erosion from that which in this paper is designated the main uplift, as 7,100 cubic miles over an area of 2,000 square miles, or about 3.5 cubic miles for

[1] *Report on the Geology of the Eastern Portion of the Uinta Mountains with Atlas*, U.S. Geol. and Geog. Surv. of the Territories, 1876.

every square mile. It is the removal of this immense load, which, in the absence of gravity anomalies, constitutes the proof of the isostatic condition of the range. In the following pages an attempt is made to elucidate the history of the range as a consequence of this condition, and to show that its general features are entirely consistent with isostatic control.

The eastern portion of the Uinta Mountains mapped by Powell comprises two structural belts, which may be distinguished as the main uplift on the north and the Yampa Plateau uplift on the south. His map is accompanied by profiles of the range, called displacement diagrams, which are depicted in a series of eleven, north-south sections as they would appear in the restored or reconstructed surface of the Point of Rocks (Upper Cretaceous) formation; and it is in these profiles that the two structural belts appear most clearly. Of the two belts the main uplift is structurally the simpler and consists of a broad anticlinal arch, rather flat in the middle but with increasing dips toward the flanks. The Yampa Plateau uplift is more complicated and comprises a secondary more acute anticline, which is separated from that of the main uplift by a syncline. It is also traversed by an axial fault with upthrow on the south. The main uplift is bounded on the north by Powell's line of greatest flexure, which is in reality a great east-west fault, as is shown on all of his sections. As a matter of convenience I shall refer to it as the North Flank fault. The width of the main uplift measured on the displacement diagrams (Fig. 1) varies from 17.5 to 27 miles with an average of about 20.5 miles. Its axis in the plan is gently curved, with concavity to the south. The south side of the main uplift is marked by steepening dips of the strata, which constitute the bounding flexure and determine the descent to the structurally lower Yama Plateau uplift.

In discussing the possible isostatic relations of the Uinta Mountains it will be convenient to consider these two belts separately. Taking up the main uplift first I shall base my estimate of the volume of rock which has been lifted above sea level, and the volume now remaining above sea evel, upon the middle four of the displacement diagrams. These are profiles Nos. 4, 5, 6, and 7, which present

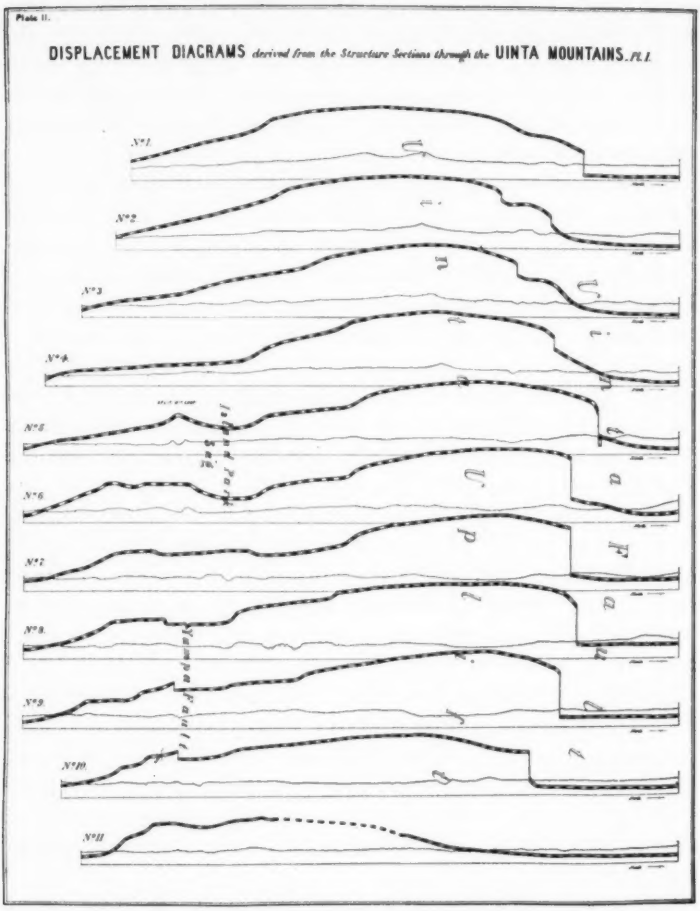

FIG. 1.—Reproduction on reduced scale of Powell's displacement diagrams, being Plate II of the Atlas accompanying his report on the eastern portion of the Uinta Mountains. Horizontal and Vertical Scale about 14 miles to the inch. The heavy broken line is the point of rock formation. The thin irregular line is the profile of the present surface, and the horizontal line is sea level.

the most characteristic cross-sections of the uplift, and I shall use the mean values derived from them. The profiles are drawn at right angles to the range at intervals of 6 miles, and the four are representative of about 24 miles of the main uplift. The width of the latter in the four profiles is 18, 20, 18, and 18.4 miles respectively, giving a mean width of 18.6 miles. The mean height above sea level of the top of the restored Point of Rocks formation in profile No. 4 is 5.43 miles; in No. 5, 5.43 miles; in No. 6, 6.09 miles; and in No. 7, 6.26 miles. There is a progressive increase in mean height from west to east, and the mean of the four means is 5.8 miles. The mean altitude of the present surface in profile No. 4 is 1.45 miles; in No. 5, 1.42 miles; in No. 6, 1.38 miles; and in No. 7, 1.25 miles. There is a progressive decrease in mean altitude from west to east, and the mean of the four means is 1.375 miles.

The initial movement in the uplift of the range occurred at the end of the Cretaceous, when the Point of Rocks formation was a shallow water deposit, the top of which was approximately at sea level. The present position of the restored Point of Rocks formation gives us, therefore, the total uplift of the range within the limits of error of the method whereby the restoration was arrived at. The restoration was evidently based upon the thickness and attitude of the strata, which are abundantly exposed at the present surface; and the estimate which the profiles express is probably as good as any that could be made. The measure of uplift afforded by the top of the Point of Rocks formation includes: (1) an epeirogenic uplift of the whole region; (2) the original orogenic arching of the range; and also (3) the isostatic rise of the range during its degradation in response to the shift of load. In the discussion which follows it is assumed that a layer of sial of specific gravity 2.7 rests on a layer of sima of specific gravity 3.

THE EPEIROGENIC UPLIFT

The consideration of the possible isostatic relations of the Uinta Mountains is somewhat complicated by the epeirogenic uplift which has affected the whole region since the end of the Cretaceous. If the range be now in isostatic equilibrium (as it presumably is) in spite of the immense load which, as Powell has shown, has been re-

moved by erosion, it owes its present configuration to a series of elevatory movements. The first of these is what may be called distinctively the orogenic upthrust, when the general anticlinal structure was initiated by the collapse of the crust under excessive compressive stress. This upthrust, whether it preceded or followed the general epeirogenic uplift, created a range distinct from the surrounding plateau. The new range under erosion lost load and, in order to maintain its isostatic balance, the column of which it was the culmination proceeded to rise, the prism removed at the surface being replaced by a thinner but heavier prism in depth. The rise went on *pari passu* with the degradation, but the mountains steadily lost height since the rise was only nine-tenths of the prism removed. Both the orogenic upthrust and the isostatic rise were independent of the altitude of the surrounding plateau. Throughout Tertiary time the products of degradation from the mountain column were deposited upon the surface of the plateau and there created a load which depressed it. The surface which was epeirogenically uplifted was, like that of the original summit of the Uinta Range, the top of the Point of Rocks formation, and this was at sea level when the elevatory process set in. It is desirable, if possible, to determine the amount of this epeirogenic uplift so that it may be discriminated from the more local or orogenic uplift of the mountains. The best data available for this purpose are furnished by the north end of Powell's eleven displacement diagrams. These show in section a belt of the pleateau on the north side of the mountains about 10 miles wide. In the eleven sections the top of the Point of Rocks formation, where unaffected by the drag of the north-flank fault, has a mean altitude of 0.555 miles. Resting on the Point of Rocks are Tertiary beds to the thickness of 0.757 miles, as a mean of the eleven sections. If this load of Tertiary rocks, which have a specific gravity of probably 2.4, were removed, the surface of the Point of Rocks formation would rise $\frac{2.4}{3.0}$ of 0.757 or 0.6055 miles. This rise added to 0.555 miles gives 1.16 miles, which is the altitude of the plateau due to epeirogenic uplift, before the deposition of the Tertiary upon it. The distinctively orogenic and isostatic uplifts of the Uinta Range are to be measured from this level.

THE OROGENIC UPTHRUST

The difference between the mean height of the top of the restored Point of Rocks formation and the mean height of the present surface is the measure in miles of the thickness of the effective, uniformly thick prism of rock removed by erosion. The loss of height is the difference between this figure and the rise of the column due to relief of load, and is, for the specific gravities adopted, one-tenth of the prism removed, the rise being nine-tenths. The thickness of the prism removed is thus $5.8-1.375=4.425$ miles; the rise of the floating column is 3.98 miles; and the loss of height is 0.44 miles. From these figures we can also arrrive at the original altitude of the range, or as it would now be if there had been no degradation. This altitude is $5.8-3.98=1.82$ miles. But this last figure includes both the orogenic upthrust and the epeirogenic uplift. The effect of the epeirogenic movement, as we have just seen, was to raise the whole region 1.16 miles. Therefore $1.82-1.16=0.66$ miles is the measure of the orogenic upthrust above the general level of the plateau.

The orogenic upthrust must have contributed to the general epeirogenic uplift, as appears from the following considerations. When the earth's crust collapsed and the anticlinal upthrust gave birth to the range, there was also a downthrust of sial nine times as large into the sima. The displaced sima was distributed as an attenuated layer in a wide region, which included the anticline in its middle part, and so lifted the surface. This redistributed sima was the exact equivalent of the mass concentrated in the mountain zone by the local collapse of the sial, and was ultimately compensated by a slight adjustment of the configuration of the spheroid. The extra load was thus disposed of by plastic accommodation into the general mass of the earth. It in no way affected the balance between the new range and the adjoining plateau.

Conversely, the rise of the column under erosion, amounting to 3.98 miles over a width of 18.6 miles, necessitated an inflow of a volume of sima to its bottom, which measured $18.6\times3.98=74$ square miles in cross section. This withdrawal of sima would cause a sagging of the flanking regions and so provide a trap for the detritus which constitutes the Tertiary formations. The latter may, there-

fore, be expected to be notably thicker near the range than in sections remote from it. The sag would have a maximum near the range and taper off to nothing away from it. If the maximum were, say, half a mile, the depression would extend out on either side of the range 100 miles.

In a previous paragraph I have shown that the rise of the main uplift column, without considering its relations to the Yampa Plateau uplift, was 3.98 miles under relief of load by erosion. This was deduced from the general assumption of a column of sial of specific gravity 2.7 floating in sima of specific gravity 3 and from the restored position of the Point of Rocks formation, as shown in Powell's diagrams. But that rise was expressed in the throw of the north-flank fault, of which we have a direct measure, also in the diagrams. The mean height above sea level of the faulted edge of Point of Rocks formation in the four selected profiles is 5.157 miles. Deducting from this the figure which we have arrived at for the pre-Tertiary height of the adjoining plateau, 1.16 miles, we get 3.99 miles as the upthrow of the range above the epeirogenically uplifted surface. The difference between the two figures, $3.99-3.98=0.01$ miles, is small and the smallness confirms Powell's judgment in his restoration of the Point of Rocks formation in profile. The practical agreement of the two measures of isostatic uplift tends to confirm the general hypothesis that the Uinta Range, and presumably other ranges of like magnitude, are prisms of sial floating in sima.

THE YAMPA PLATEAU UPLIFT

If we consider the Yampa Plateau uplift as a whole in the same four profiles, the mean height of the restored Point of Rocks formation is 2.88 miles and the mean altitude of the present surface is 1.16 miles. The prism removed by erosion is 1.72 miles thick, the rise of the column in response to this removal has been nine-tenths of this or 1.55 miles, and the loss of height has been 0.172 miles. The mean altitude of the Point of Rocks formation before erosion was $2.83-1.548=1.33$ miles; but of this 1.16 miles was due to epeirogenic uplift so that the orogenic upthrust was only .172 miles. It appears from these figures that the loss of height is equal to the original upthrust, and that the present surface coincides with the

surface due to epeirogenic uplift. The mountains, as distinguished from the plateau, have thus been completely wiped out, as features of the relief, though of course their basal structure remains. The hypsometric contrast between the restored profile of the Yampa Plateau uplift and that of the main uplift is due to this circumstance. The isostatic rise in the one case was much less than in the other, being in direct proportion to the thickness of the prism removed. Since the rise of the main uplift due to relief of load is 3.98 miles and that of the Yampa Plateau uplift only 1.55 miles the difference between these figures, or 2.43 miles, is the measure of the displacement between the two mountain belts. This displacement is distributed in the stratified rocks near the surface in a broad flexure, but in depth in more massive rocks may take the form of a fault.

THE BLACK HILLS

The general structure of the Black Hills, so well described by Darton and Paige,[1] is even simpler than that of the Uinta Mountains; and for purposes of comparison I have attempted to outline their historical development, on the assumption of isostatic control. This range, like the Uinta Mountains, is a simple broad anticline in a region of epeirogenic uplift. Both the epeirogenic and orogenic movements date from the close of the Cretaceous; and the top of that series, if restored to its deformed position, affords a measure of uplift and of degradation. Darton has given us this restoration in his Figure 38, and from it I gather that the mean altitude of the top of the Pierre shale in the central part of the Black Hills, for a width 38 miles, is about 2.39 miles. In the same section the mean height of the present surface is 1.16 miles. The prism removed is the difference between these figures or 1.23 miles. The isostatic rise, on the assumption of the sial having a specific gravity of 2.7 and the sima 3, is 1.23×0.9 or 1.1 miles; and the loss of height is 0.12 miles. The difference between the mean altitude of the top of the Pierre and the isostatic rise, 1.28 miles, is the original altitude of the uplift before erosion. But this includes the epeirogenic uplift, which was about 0.6 miles, so that $1.28 - 0.6$ or 0.68 miles is the measure of the original orogenic upthrust, considered as an effective level topped

[1] *U.S. Geol. Surv., Folio 219.*

prism, above the pleateau due to epeirogenic uplift. The top of the real anticlinal arch may have been twice as high above the plateau as the corresponding effective prism.

The isostatic rise of the Black Hills column under erosion would induce a shearing stress between it and the adjoining plains. This shear may find its expression in the down-flexure of the strata on the east side of the uplift shown in the sections of the folio. On the west side we have a suggestion of a fault, with upthrow on the east, shown in the configuration of the surface of the Minnekahta limestone, Figure 6. The withdrawal of sima from the flanks of the uplift to compensate the rising column would cause a sag on either side. The synclinal depression of the Minnekahta limestone on both sides of the uplift, as shown in Figure 6, may be the expression of such a sag.

PALEOZOIC CHERTS OF WEST-CENTRAL VIRGINIA[1]

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ABSTRACT

It is the writer's contention that the various cherts which are found associated with the Paleozoic formations of west-central Virginia can be distinguished from each other. To this end descriptions of the distinguishing features of these cherts are given.

Cherts and flints are conspicuous constituents of most of the Paleozoic limestones of west-central Virginia, and in many places they are a convenient and usable stratigraphic guide in the identification of the particular formation from which they are derived. It is the thesis of this paper that cherts of individual horizons may be distinguished from cherts of other horizons, and that a knowledge of the characteristics of the cherty material of this region is of considerable importance to the field geologist. This appears to be especially true in the case of the "Cambro-Ordovician" or Valley limestones, whose various members differ so slightly from each other that any assistance in their stratigraphic recognition is of special importance. The area here described as "west-central Virginia" includes Roanoke, Craig, and Botetourt counties, and adjacent parts of Montgomery, Giles, and Alleghany counties. It extends from the Blue Ridge on the east and south across the Great Valley and the Alleghany Mountains to the West Virginia boundary. It lies midway between Maryland and Tennessee, and west of the central part of Virginia.

Considered mineralogically, chert consists of cryptocrystalline quartz having light colors, generally white or gray. Flint is similar but exhibits dark colors, chiefly black. For the purpose of this paper, no distinction will be made between flint and chert, and all such material will be described under the single term chert, both for convenience and also because the field geologist working in this region finds no need for such a discrimination. Considered stratigraphically, chert and flint occur in the same manner.

The cherts of this region occur in three ways: (1) As separated

[1] Published with the permission of the Virginia Geological Survey.

nodules or smaller knobby masses in the bed rock; (2) as thin persistent lenticular layers or lenses in the bed rock; and (3) as more or less solid irregular masses of various sizes, generally in the residual soil and grading downward into the bedrock. The cherts are found in limestones and dolomites, and their occurrence appears to be limited to essentially calcareous rocks. They are commonly described as being most abundant near the upper part of the formations, a fact which is important in considering their origin. So far as has been observed, the nodular cherts occur along bedding planes or other structural zones, whereas the massive cherts partake of the minor structures of the enclosing formation. In certain formations such as the Becraft or Keyser limestones, the cherty layers are only a few inches apart, and they persist through a considerable vertical distance as well as having a wide geographic distribution. In other formations, as in the Nittany dolomite, the chert appears only on exposed and weathered surfaces, and its occurrence is very irregular both stratigraphically and areally.

The Virginian cherts may be grouped into three prominent color varieties, namely black, grayish white, and white. Other colors modify individual fragments or even larger masses, but these three colors prevail. The black cherts are commonly dark gray on the surface due to weathering and oxidation. The gray cherts have much the same color throughout and some are concentrically banded. They may be greenish, due to surface incrustations of lichens and similar plant growth. The white cherts are often brilliantly white within, but may be stained deep red or brown on the surface from the residual soils in which they occur.

Several distinct varieties of cherts can be readily distinguished by their texture and structure. A common type is the nodular variety which is massive, with true conchoidal fracture, and with rounded surfaces. A second type occurs as thin, slabby masses having irregular porous surfaces, and weathering to platy slabs an inch or more thick and several inches wide and long. A third variety is massive, dense, and very hard, having jagged surfaces with many sharp edges. This type has abundant fracture planes along which it breaks, and occurs in masses several feet in diameter. A very few of the Virginia cherts are mealy and porous, resembling worm-eaten wood. They

are commonly crumbly on the surface. Such chert is abundant in the Chepultepec dolomite of Alabama, but is rare in west-central Virginia.

Many of the Virginia cherts are fossiliferous, although sparingly so. The fossils occur predominantly as silicified casts of the interior of shells, with gastropods, bryozoa, and cephalopods as the more common types to be preserved. The fossils are seldom complete, and it is generally very difficult to extract the fossil from the chert in which it is found. Upon many limestone or dolomite outcrops scores of unfossiliferous chert fragments will be found for every fragment containing fossils, although it is a common experience to find that a chert boulder which contains one fossil form will carry several more. Thus, on an outcrop of the Nittany dolomite, the observer may handle one hundred pieces of chert without finding any trace of fossils, whereas the next fragment he examines may contain five or six fossil shells. In all specimens observed, the fossils of the chert are entirely similar to those of the containing rock, differing only in manner of preservation.

In this part of Virginia, the cherts are best developed upon hill slopes and uplands, and it is difficult to avoid the conclusion that this occurrence has an essential relation to the method of chert formation. In many places the cherts are so abundantly strewn upon the surface of the Valley limestone belt that fertility of the soil is impaired. Thus many of the chert areas have never been cleared for agriculture. These cherty areas are readily subject to drought, and even where cleared the soil may therefore be barren and sterile. It is a common experience to find such areas bounded by stone fences built of the chert fragments cleared from the land. The cherty ridges were often covered with a scraggly growth of chestnut, hickory, or cedar, and Cedar Ridge, Hickory Ridge, Chestnut Ridge, or Timber Ridge are common topographic names in the areas of chert outcrops.

In many places the residual soil from a calcareous formation contains abundant chert, whereas a near-by road cut or stream gorge through the underlying bed rock exhibits no cherty material. Thus the area of the Nittany dolomite is readily recognized by a mantle of soil carrying its characteristic chert in abundance, while fresh exposures of the Nittany are chert free.

Most of the chert resists erosion and weathering to such an extent that it does not become rounded even after long transportation or exposure. Hence, nearly all chert fragments are angular except those boulders which were originally round.

Formations from which chert is derived in west-central Virginia are as follows:

Devonian	Oriskany horizons Becraft limestone
Silurian	Keyser formation
Ordovician	Lenoir limestone Lower Stones River limestone
"Cambro-Ordovician"	Nittany dolomite Jonesboro formation
Cambrian	Elbrook formation Shady dolomite

From each of these calcareous formations, cherty debris accumulates in variable amounts. While it is not the contention of the writer that each of the foregoing formations may always and at each exposure be identified by its chert, it is his field experience that there are striking differences in the cherts of the different units. The lithology, stratigraphic position, and fossil content will serve to determine the identity of many of the formations in question. In the absence of other distinctive features, however, the chert may be the most convenient guide for identification, and it is in places the only apparent surface clue to the identity of the underlying formation.

Short descriptions of the individual cherts of the foregoing formations follow. It should be kept in mind that these descriptions should not be applied solely to isolated fragments but rather to the average of a collection of cherts from the horizon in question.

Oriskany chert.—Little chert is known in this region from Oriskany horizons. This is surprising in view of the abundant chert in this zone in northern Virginia and other areas. The Shriver chert of Maryland, lying below the Ridgeley sandstone, and the Huntersville chert of eastern West Virginia, lying above the Ridgeley sandstone, are conspicuous chert horizons. In west-central Virginia, however, the Oriskany sandstone is very thin and chert free. At the

Oriskany iron mines near Lignite, Botetourt County, the footwall of the workings is a ferruginous sandstone containing scattered fragments of white chalcedonic chert. This is the only observed occurrence of chert in this horizon in the area under consideration, and the chert was not observed elsewhere than at the mines.

Becraft chert.—The chert of the Becraft limestone occurs in some abundance near the middle of the formation in horizontal layers which conform to the bedding of the rock. It is in black nodular masses, some of which are 6 to 8 inches thick and grading down to layers less than 1 inch thick. The chert contains fossils similar to those in the containing rock, but the fossils are less common and more poorly preserved than in the limestone. Much of the chert has a pitted surface, and the nodules are extremely irregular in shape and size. On the weathered surface of a cliff, the chert layers stand out in relief several inches beyond the surface of the limestone. The whole appearance of such an exposure is very similar to the surface of the cherty Onondaga limestone of western New York. The Becraft limestone does not give an especially cherty area of outcrop, since the chert occurs sparingly through the formation as a whole.

Keyser chert.—In the Keyser limestone, chert occurs in two zones separated by an arenaceous limestone. The lower zone is a massive, dark limestone in which the chert appears in definite lenses. The upper zone consists of a medium-bedded nodular and cherty limestone with abundant chert scattered through the entire thickness. The chert is dark gray to black with an interior which is slightly lighter. Thus the cherty nodules have a pseudo-augen appearance in a cross section of the formation. Much of the chert is in nodular layers, each nodule being oval in cross section and parallel to the bedding of the formation. These nodules are separated from each other by thin, shaly partings—the whole producing a reticulate mesh not unlike the effect shown by the leaf-scars of *Lepidodendron*. The nodules are from 2 to 3 inches wide and about 1 to 1½ inches thick. As in the Becraft limestone, the chert of the Keyser limestone is only sparingly distributed over the area of its outcrop.

The Ordovician formations, Lenoir and Lower Stones River limestones, carry small amounts of chert. Neither of the formations contains sufficient chert to distinguish it from other formations.

Lenoir chert.—The chert of the Lenoir limestone is nodular and the nodules are small, so that the chert fragments are generally only an inch or so in diameter. Lenoir chert is more commonly found in rounded fragments than the chert of any other formation in the district, but this roundness is original rather than the result of abrasion or weathering. The Lenoir chert is dark brown or black and carries fossils, which are chiefly fragments of trilobites and brachiopods.

FIG. 1.—Chert on exposure of the Lower Stones River limestone. Rich Patch Valley, Alleghany County, Virginia.

Lower Stones River chert.—The chert of the Lower Stones River limestone is likewise nodular, but weathers chalky white and has a steel-blue interior. This chert occurs in layers much as does the chert of the Becraft limestone, and the cherty lenses are prominent on weathered ledges. The chert contains fossils chiefly of bryozoa which have been largely dissolved leaving external molds (see Fig. 1).

Nittany chert.—The Nittany dolomite is by far the most abundant chert formation in this region. Great numbers of chert fragments in its soil are characteristic of and serve to identify the belts of its outcrop. Common features of the Nittany outcrop are hill slopes covered with scattered chert masses and fields bounded by stone piles or fences of the chert. The chert is gray or dirty white and always

occurs in dense, tough, hard, massive, and generally jagged fragments which remain angular despite abrasion by transportation and erosion. The chert boulders may range up to a yard in diameter but are commonly about the size of a grapefruit. This type of chert can always be distinguished by its dense, jagged nature. The surfaces of the chert fragments are as a rule slightly stained with hematite, so that the fracture planes are sometimes reddish. In many of the fragments, at least one of the surfaces is covered with a pseudo-

FIG. 2.—Residual chert in weathered soil of the Nittany dolomite, Rich Patch Valley, Alleghany County, Virginia.

pappilose marking which resembles the surface of *Lithothamnium*. Some of the chert is mealy in appearance, not unlike wormy timber. The Nittany chert is best developed on hillsides. Where the formation outcrops in low areas, or is exposed in fresh cuts, little or no chert is found (see Fig. 2). Where the formation is horizontal, the cherty material generally forms low, wooded hills.

In this region, the presence of abundant whitish, jagged, dense cherts can be relied upon to indicate an outcrop of the Nittany dolomite, although the absence of such cherts does not preclude the presence of the formation, which may be unmarked by cherty debris.

Fossils in the Nittany chert silicified casts of the interiors of such shells as *Lecanospira*, *Hormotoma*, and *Roubideauxia*. The fossil-

iferous cherts are very rare in comparison to unfossiliferous fragments, sacrcely one chert fragment in one hundred containing fossils.

Jonesboro chert.—Directly below the Nittany dolomite is a thick series of limestones and dolomites which represents the Jonesboro formation of Tennessee and possibly the Copper Ridge formation. This formation is the great chert horizon of the southern Appalachian Mountains. In Alabama the Copper Ridge carries jagged chert similar to that found in the Nittany dolomite of this region. In west-central Virginia, however, the Jonesboro formation is largely chert free. The chert derived from this formation is black, slabby, and generally has pitted or rough surfaces. Thin slabs of chert about an inch thick characterize the chert debris of this formation. At a few horizons in the Jonesboro, thin sandy zones contain cherts that are brilliant, chalcedonic white, and chalky on weathered surfaces. These cherts readily break into tiny angular fragments which are commonly deeply stained on the surface with the red color of the residual soils. Such cherts are not common and are less conspicuous than the sandy lenses with which they appear to be associated.

Elbrook chert.—The writer has not observed abundant chert at any point on the outcrop of the Elbrook limestone, and the chert known to come from this formation is thin, slabby, and black. If differs but slightly from the slabby chert of the Jonesboro formation, although the Elbrook chert is generally much less abundant and in smaller fragments than the Jonesboro chert.

Shady chert.—The outcrop of the Shady dolomite at places affords chert which varies in general appearance. Two distinct types are common: (1) a cavernous ferruginous chert with quartz druses is associated with the residual deposits of iron and manganese in the Shady dolomite; (2) nodular chert with gray surfaces and with concentric gray and black bands in the interiors is found in some of the residual soils of the formation. As outcrops of the Shady are generally near outcrops of the older Cambrian quartzites, the Shady belts are commonly covered with quartzite float to such an extent that chert residuals are inconspicuous.

Several other formations of this area are calcareous but none contains chert in appreciable amounts, so that the occurrence of chert in the residual soil implies the presence of one or more of the fore-

going formations. This is so conspicuously true in the case of the Nittany dolomite that an area strewn with heavy chert fragments is considered to be a Nittany outcrop until proved otherwise.

ORIGIN OF CHERT

Although the present paper makes no attempt to contribute to the various theories of the origin of chert, several observations on the occurrence of chert in Virginia appear to have a more or less pertinent bearing upon the age relations and manner of origin of the particular cherts in question. The following observations seem significant:

1. The cherts are prevailingly abundant upon the weathered exposures and in the residual soils of certain formations but they are conspicuously absent in the fresh bed rock of these same formations.

2. The cherts do not appear to be characteristic of any given horizon in the formation, but appear to favor certain definite types of topographic expression of the formation.

3. The chert which is known to occur in the bed rock generally occurs near the top of the formation, which in most cases means that the cherty lenses occur directly below an unconformity or old denudation surface. It might also be pointed out that the top of any given formation quite often also means the top of the examined exposure.

4. It is a common occurrence to find the cherty ledges and masses at the surface grade downward into unsilicified calcareous bed rock below. This is also true on a smaller scale of many of the fossils which are silicified on the surface but are calcareous within.

5. The majority of the cherts have the same general structures as the enclosing rock, and if they are in lenses, these lenses conform with the bedding planes of the rock.

6. The cherts of the "Cambro-Ordovician" group show a strong tendency to appear at similar elevations throughout any local area, and to be absent at elevations above or below this zone of concentration.

Because of these observations, the writer is strongly inclined toward the view that the chert is epigenetic and was formed subsequently to the formation of the enclosing rock. It would further

seem probable that the development of the chert is a function of surficial weathering, since so great a proportion of the chert is associated with present or past denudation surfaces, whereas the chert is so rare in the fresh, unweathered rock. The idea has been proposed, with which the writer concurs, that some of the normal silica content of rocks adjacent to the present position of the cherts has entered into colloidal suspension during decomposition of the rock under subaerial weathering, and that this silica has been segregated and redeposited as a replacing agent in the metasomatism of certain calcareous horizons which probably had some inherent character favoring such replacement. The main tenets of this explanation were first proposed by Ulrich[1] in an attempt to explain the cherts of the Potosi group in Missouri.

The writer is inclined toward this theory of origin of these cherts in Virginia for several reasons. (1) That the chert is so abundant upon the outcrops of certain formations and is so rare in the unweathered bed rock directly below the chert residuals appears to be a strong point in favor of the superficial nature of the process of chert formation. (2) That the cherts take on the same structures as the containing beds points strongly toward a replacive origin subsequent to the formation of the containing rock. (3) That cherty beds at the surface grade downward into chert-free calcareous beds is likewise suggestive of replacement connected in some necessary manner with the surface exposures. (4) The presence of the chert in lenses parallel to bedding planes points toward the use of such planes by migrating waters, and the occurrence of such lenses below unconformities suggests weathering surfaces other than the present one along which such chert formation might have progressed. (5) The association of cherty residuals, as on the Nittany dolomite, with definite topographic types and at rather uniform levels is scarcely explicable without invoking surface agencies in production of the chert.

It would appear in accordance with the theory of replacement by weathering that the greater amounts of chert should develop from calcareous formations having large areas of outcrop, whereas chert

[1] E. O. Ulrich and H. F. Bain, "The Copper Deposits of Missouri," *U.S. Geol. Surv. Bull. 267* (1905), pp. 27, 30.

in formations whose outcrops are small should be associated with former widespread exposures. This is borne out by the facts. The more abundantly cherty formations are the Nittany, Jonesboro, Shady, and Elbrook formations whose outcrops are extensive. In the Lower Stones River, Lenoir, Keyser, and Becraft formations whose present outcrops are small, the chert occurs in lenses below former erosion and weathering surfaces. It is thus believed that the cherts of the first group of formations have been largely derived from comparatively recent weathering, while the cherts of the second group may have been derived from weathering during periods of exposure now represented by the unconformities which directly follow the formations.

The present discussion of the cherts of west-central Virginia makes no attempt to comment upon other theories of the origin of cherts, nor upon the objections to the replacement theory. The writer has been unable to find in this region definite evidence that the cherts are syngenetic or contemporaneous in origin with the containing or producing rock. The evidence observed points strongly toward an epigenetic origin for the cherts in question, with replacement of calcareous beds by colloidal silica during subaerial weathering as the immediate process of formation.

GRANITE INTRUSIONS IN THE HURONIAN FORMATIONS OF NORTHERN MICHIGAN

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ABSTRACT

A number of granite dikes intrude the Huronian formations of northern Michigan. These dikes closely resemble the porphyritic granite of the Southern complex and are thought to have emanated from that granite massive. If this is the case, at least some of the granite of the Southern complex is post-Huronian rather than Archean, is responsible for some of the intense metamorphism of the Huronian formations, and is probably closely related to the tectonic forces that caused the close folding in that area.

INTRODUCTION

In the northern peninsula of Michigan, in general south of the Marquette iron-bearing district, there is a large granitic area which was originally mapped as the Southern complex.[1] This Southern complex consisting of granite and the Palmer gneiss was designated as Archean. The granite is shown as occupying most of the area, whereas the Palmer gneiss is shown, for the most part, as a zone bordering the granite, principally in the vicinity of Palmer.

For many years it has been known by Professor A. E. Seaman, of the Michigan College of Mining and Technology, that around the periphery of the Southern complex there are to be found granite dikes intruding Huronian sediments and that apparently a metamorphic aureole exists around the periphery of the granite found in this Southern complex. Recently the Michigan Geological Survey,[2] following suggestions made by Professor Seaman, has called attention to some of these relations.

In this article the writer desires to describe some of the field phenomena observed in this area and to call attention to some probable interpretations based on these phenomena. It should be stated

[1] C. R. Van Hise and W. S. Bayley, "The Marquette Iron-bearing District of Michigan," *U.S. Geol. Surv. Mono. 28* (1897); C. R. Van Hise and C. K. Leith, "The Geology of the Lake Superior Region," *U.S. Geol. Surv. Mono. 52* (1911).

[2] C. O. Swanson, *Report on the Portion of the Marquette Range Covered by the Michigan Geological Survey*, in 1929, pp. 2, 13–15. L. P. Barrett, F. G. Pardee, and W. Osgood, Geological Map of Iron County, 1929.

at the outset that final conclusions are not possible at this time, as insufficient field work has been done and as yet no detailed petrographic study of specimens collected has been made.

The writer is indebted to Professor Seaman for helpful suggestions and guidance in the field work done during the latter part of the summer of 1930, and for information furnished some years ago while the writer was a student in his classes.

THE GRANITE DIKES

During the course of a brief reconnaissance investigation of portions of the Huronian rocks surrounding the main granite area of the Southern complex, numerous granite dikes intruding those rocks were observed. These dikes vary in width from about 1 foot to 50 feet and were found in rather widely separated localities, as shown by the accompanying map (Fig. 1). They intrude Lower and Middle Huronian formations and probably also are intrusive into the upper Huronian. A few typical cases will be described briefly.

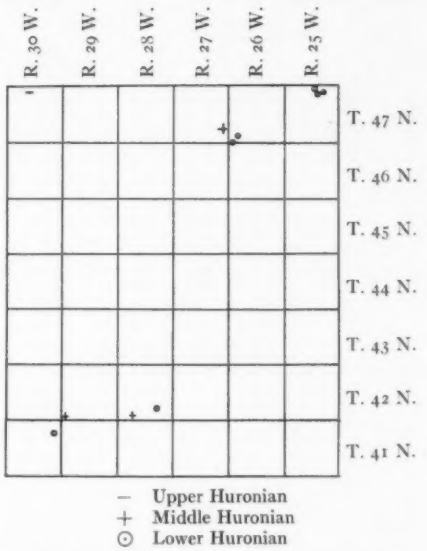

FIG. 1.—Map showing location of some of the granite dikes intruding the Huronian formations.

The Lower Huronian formations have been intruded in both the southern and northern parts of the area. The more southerly intrusions found are in the Sturgeon quartzite and the Randville dolomite, while the northerly intrusions are in the Mesnard quartzite and probably in the Kona dolomite, the equivalents of the southern formations. Only two illustrations need be cited.

Southeast of Randville, in Sec. 12, T. 41 N., R. 30 W., the Lower Huronian Sturgeon quartzite is cut by at least five granite dikes

within a distance of 500 feet (Fig. 2). These dikes vary in width from 1 foot or less to about 50 feet. They consist of a reddish, rather coarse-grained, somewhat porphyritic granite which contains biotite in some places. Some of these dikes send out small stringers into the intruded quartzite, and these stringers often pass into quartz veins. As will be seen from the outcrop map, two of the northerly trending dikes contain xenoliths of quartzite, the larger of which is about 18 by 45 feet.

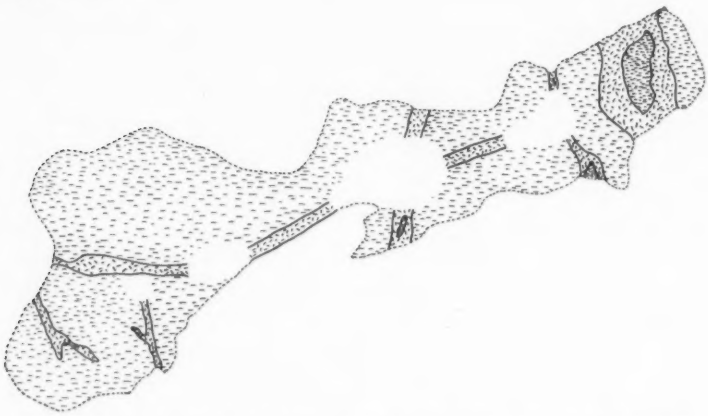

FIG. 2.—Outcrop map showing granite dikes cutting the Sturgeon quartzite. The large dike farthest east, enclosing a block of quartzite, is about 50 feet wide.

East of Felch, in Sec. 26, T. 42 N., R. 28 W., there is a marble quarry in the metamorphosed Randville dolomite, the Lower Huronian formation next above the Sturgeon quartzite. In this quarry the Randville dolomite is cut by three granite dikes within a distance of 200 feet. The central one of these dikes is well exposed in the southerly and northerly quarry walls (Fig. 3). It is about 2.5 feet wide and is composed of a reddish granite which contains, in places, feldspar phenocrysts an inch or more across. The other dikes in this quarry are somewhat more rhyolitic in character.

From the foregoing illustrations, and others that might be described in detail, it appears clear that the Lower Huronian has been intruded by granite dikes in several localities.

At least three rather clear examples of granite dikes intruding the Middle Huronian might be cited, two intruding the Negaunee iron formation southeast of the Crystal Falls district and one showing intrusion into the Siamo slate in the Marquette district. Of those cutting the Negaunee iron formation, one about 12 feet wide may be observed at the old Groveland pit (Sec. 31, T. 42 N., R. 29 W.), and one about 18 feet wide at Felch, some 7 miles farther east. These dikes are composed of reddish, porphyritic biotite granite. The one at Felch shows the relations very clearly, as its trend is nearly at right angles to the strike of the iron formation and it weathers more rapidly than the latter, so that the iron formation projects above the granite on the eastern side of the dike (Fig. 4). A very good illustration of intrusion into the Siamo slate, which underlies and grades up into the Negaunee iron formation, may be found slightly to the northwest of the west end of Lake Palmer, in Sec. 25, T. 47 N., R. 27 W. There a reddish, coarse-grained granite dike is exposed near the top of a high bluff and can be seen very well from some distance, as the rather white, weathered surface contrasts strongly with the dark Siamo slate.

FIG. 3.—Dike cutting Randville dolomite. Looking north.

Although it is believed that further work in the Upper Huronian will disclose dikes similar to those found in the Lower and Middle

Huronian, the evidence found so far is more indirect than that previously cited. Along the shores of Lake Michigamme, and on islands in the lake, some of the Upper Huronian formations, especially the Michigamme graywacke-slate, are well exposed. On a small island near the southern end of the lake, in Sec. 4, T. 47 N., R. 30 W., the Michigamme graywacke-slate is intruded by pegmatitic veins. While these veins consist mostly of quartz, they contain, also, small amounts of feldspar and mica, and closely resemble the

FIG. 4.—Granite dike cutting Negaunee iron formation. The contacts are marked by the stick in the foreground and the geological pick resting against the iron formation. The dike is about 18 feet wide. Looking northeast.

quartz veins so frequently observed emanating from the granite dikes previously described. It is thought that these quartz veins represent similar offshoots from granite at no great distance away, as the graywacke-slate has been extensively metamorphosed and is a knotty schist, or *knotenschiefer*, containing crystals of garnet, staurolite, andalusite, and tourmaline. Some of the staurolite and andalusite crystals are $\frac{1}{2}$ inch to 1 inch across. Another significant thing is the fact that the best developed and largest andalusite crystals are found near the contact between the slate and the quartz veins. Metamorphism of this character is not confined to this small island but was observed also along the southeastern shore of the lake.

METAMORPHISM

The Huronian rocks surrounding the granitic area under consideration are closely folded and extensively metamorphosed, but much of the metamorphism indicates that it is due to the intrusion of some large igneous mass, and typical contact metamorphic minerals may be found throughout the entire range of the Huronian formations. In places the Lower Huronian Randville dolomite has been converted into a marble containing radiating and interlocking tremolite crystals, pyroxene near salite, probably wollastonite, feranthophyllite, and a number of other minerals of similar origin. In the Negaunee iron formation (Middle Huronian), grünerite, garnet, and magnetite are conspicuous. Mention has already been made of the development of garnet, staurolite, andalusite, tourmaline, and biotite in the Upper Huronian Michigamme formation. A detailed petrographic study of these Huronian rocks, which is being undertaken by the writer, will doubtless disclose the presence of many other contact metamorphic minerals.

It seems apparent from the foregoing brief illustrations that the Huronian formations show evidences of metamorphism of a type indicating that it was developed by some large igneous intrusion. Since the Huronian formations are known to have been intruded by granite dikes, and since the only large igneous mass in the region under consideration is the granite of the Southern complex, which is very similar to the granite dikes, it seems logical to consider the possibility that this large granite mass may be the cause of this metamorphism as well as the source from which the dikes emanated. It is desirable, therefore, to describe briefly some of the features found within this granite massive and toward its periphery.

THE SOUTHERN GRANITE

The granite of the Southern complex, except near the periphery of the mass, is strikingly porphyritic. It is mostly a pink to red granite containing large feldspar phenocrysts, often 1.5 inches long and $\frac{1}{2}$ inch across, quartz in rather small crystals as a rule, and usually some biotite. It appears to be rather uniform throughout the entire area, outcrops near Gwinn closely resembling those near Republic, about 30 miles farther west. A pegmatitic facies of the granite has

been observed in numerous places, and the main granite mass is cut, in some cases, by coarsely pegmatitic dikes of the same character. It seems likely that these pegmatitic dikes represent the same general period of intrusion, as they closely resemble the pegmatitic facies into which the main granite grades in many places.

In addition to being strikingly porphyritic there is usually a parallel orientation of feldspar phenocrysts, schlieren, and such features. If this granite of the Southern complex is in reality post-Huronian, it appears that a detailed study of it, using the methods developed by Professor Hans Cloos[1] and applied by Robert Balk,[2] J. T. Stark,[3] and others in this country, should show a close relationship between the primary structure of the granite and the major folding of the Huronian formations. Time for such detailed study was not available during the writer's reconnaissance work this summer. However, some observations were made, especially in the region around Republic. Those observations near Republic, about twenty-five in number, show that there is a general northwest-southeast orientation of the feldspar phenocrysts, roughly parallel to the axis of the Republic trough. But much more detailed work throughout the entire granite area will be necessary before definite conclusions can be drawn. Nevertheless, these observations, throughout an area at least 10 miles in length, are suggestive, especially when considered in connection with the granite dikes found intruding the Huronian formations, the type of metamorphism that exists in many places, and some of the features found near the periphery of the granite mass.

As one passes from the interior of the granite area toward its margin, it is observed that near the periphery the granite is much finer textured than toward the interior. Moreover, at no place has the writer found a sharp contact between the granite of the Southern

[1] Hans Cloos, *Tektonik und Magma Untersuchungen zur Geologie der Tieten* (Berlin: herausgegeben von H. Cloos, 1922); *Das Batholithenproblem* (Berlin: Gebr. Borntraeger, 1923); *Einführung in die tektonische Behandlung magmatischer Erscheinungen* (Granittektonik) (Berlin: Gebr., 1925).

[2] Robert Balk, "Structure of Granite Massives," *Bull. Geol. Soc. Amer.*, Vol. XXXVI (1925), pp. 679–96.

[3] J. T. Stark, "The Primary Structure of the Kekequabic Granite," *Jour. Geol.*, Vol. XXXV (1927), pp. 723–33.

complex and the Huronian formations. In general, between clearly recognizable granite and undoubted Huronian formations there are three types of areas: (1) an area in which there are a few scattered outcrops of a somewhat schistose granitic rock; (2) an area characterized by a gneissoid rock which in places closely resembles the Huronian formations thoroughly injected with granite and which in other places resembles a granite area in which the granite has absorbed a large amount of other material; (3) a swampy area devoid of outcrops. These contact relations appear to be in harmony with the supposition that the granite is intrusive into the Huronian formations and are also in harmony with the contact relations of the dikes which cut the Huronian. As a rule these dikes do not have a welded contact, but the contact line in many places is marked by (1) a schistose material which is often very non-resistant, as at the marble quarry east of Felch (Fig. 3), or (2) a somewhat more resistant material which has the appearance of a schistose granite, as in Sec. 3, T. 47 N., R. 25 W. Material of the first type, because of its non-resistant character, might easily give rise to swampy areas devoid of outcrops when developed on a large scale around the main granite intrusion, whereas material of the second type could produce areas containing scattered outcrops of schistose granitic rock. The gneissoid rocks could very easily be formed by the granitization of a quartzite. This is clearly illustrated on a small scale in Sec. 12, T. 41 N., R. 30 W., where the Sturgeon quartzite has been extensively intruded by granite.

It is realized that the suggestions regarding the granite of the Southern complex are based on rather limited field work. However, the writer expects to supplement this reconnaissance work with a detailed petrographic study of the specimens collected, and with extensive detailed field work next summer. Regardless of the final conclusions with respect to the granite of the Southern complex, the fact that the Huronian formations have been intruded by granite dikes is clearly established. Obviously these dikes must have had some source, and the granite of the Southern complex is the only large granite mass in the area under consideration.

REVIEWS

Die Oszillations-Theorie: Eine Erklärung der Krustenbewegungen von Erde und Mond. By ERICH HAARMANN. Stuttgart: Ferdinand Enke, 1930. Pp. 260; figs. 78; 1 map.

In this interesting contribution to the literature of diastrophism Professor Haarmann demands nothing less than a complete separation of this branch of geological science from the hypothesis that its causal forces originate in earth contraction. By sounding a new note in the geo-tectonic medley, his theory gives the impression of being a reaction from the widely current views of extreme crustal mobility. This hypothesis is based squarely on the assumption that the earth cooled from a molten condition and in so doing developed a thin solid crust.

Bringing to the aid of geology observations of neighboring cosmic bodies, he points out that the sun is developmentally younger than the earth. A more rapid equatorial than polar rotation indicates that this body strives to maintain a condition of mass equilibrium by means of horizontal flowage in addition to the well-known vertical movements. He assumes that the currents of the infantile earth were analogous to those of the sun.

The freezing of a solid crust before a condition of complete stability had been attained in the earth's interior hindered and perhaps stopped the process of surficial horizontal flowage as an adjustment to local disturbances of equilibrium. Below the surface, however, vertical and horizontal currents continued in response to the recurrent need for internal isostatic adjustments, the resulting crustal movements forming protuberances and depressions to which are applied the terms "geo-tumor" and "geo-depression."

It is admitted, however, that the moon may have been born from the body of the earth in those early days, and that the youthful earth's crust may have broken and slid laterally. The scar remaining after the separation of the satellite would have been the greatest existing hiatus of "sima" and might have furnished primary slopes down which the sliding crust could have moved, "balling" itself together as the greatest known concentration of "sial." Forming the continent of Asia, this outstanding granitic body, and not the Pacific Ocean, marks the former position of the moon's mass. The development of geo-tumors and geo-depressions in

response to an internal striving toward mass stability is called "primary tectogenesis."

The moon has no atmosphere and experiences no erosion, except that due to the influence of temperature changes and gravity. Though developmentally older than the earth, the moon still displays in the "walled plains" a great series of geo-tumors which swelled upward, due to the rise of subcrustal magma, and later collapsed when the fluid mass was partly withdrawn. A similar "scoriosphere" which presumably exists within the earth's crust has been obscured by the processes of erosion and deposition.

The development of geo-tumors during the earth's past history, if not occurring within the continents, has given rise to such areas; geo-depressions have become the ocean basins and geosynclines. Denudation of the primary elevations and the ensuing deposition have caused elongate masses of sediment to appear on the slopes of these features. Where the primary slope has been sufficiently steep and the sediments adequately thick and plastic, orogeny has resulted through the sliding of these strata basinward under the influence of gravity. Such movements gave rise to the folds, overthrusts, etc., of many mountains. Under the influence of this surficial movement the hinterland on the geo-tumor was subjected to tension and fracturing, which facilitated the rise of magma and the development of batholiths and volcanoes. "Secondary tectogenesis" is the name applied to such a process of displacement caused directly by the effect of gravity. It includes the thrusting or compression of the border-zone sediments as well as the tension and tearing apart of the hinterland.

If the dislocated sediments came to rest at the bottom of the slope, the resulting structure was asymmetrical or one-sided, the faults and folds being chiefly overthrust and overturned. Such an orogeny is called "free-gliding." Where the geosynclinal sediments completely filled the depression, however, the displacements acquired a bilateral symmetry due to the resistance of the opposing slope. Folds in general were upright, and fault planes were nearly vertical. This orogeny is known as "full-trough-gliding."

As a change of phase was inaugurated, the normal and uninterrupted continuation of primary crustal oscillations eventually raised the geo-depression, then filled with an orogenic massif, and formed highlands. The original hinterland subjected to tension and intrusion was, on the other hand, brought low. With the relative position of these two primary features reversed, the stage was once more set for the development of new

bodies of plastic sediments on the primary slopes, the eroding orogenic massif of the preceding cycle furnishing the material.

There follows a summary of the processes in the author's own words:

A relatively quiet oscillation followed by degradation in the highlands and deposition in the lowlands; initiation of secondary tectogenesis as soon as the limits of balance have been exceeded; introduction of stronger vertical movements and more intensive secondary tectogenesis manifested in compression down the slope and tension up the slope; vulcansim especially in the elevated regions and in the depressions; reversal in the movements of oscillation causing the compressed sediments to be raised to high mountains.

The failure of secondary tectogenic massifs to appear on the moon is due to the absence of geosynclinal sediments which cannot be produced without erosion. Hence, no erosion and deposition—no orogeny!

Professor Haarmann is to be complimented on his bold attempt to utilize extraterrestrial observations in explanation of earthly processes, though it is the reviewer's opinion that the walled plains of the moon have a significance other than that attributed to them. The uniformly circular plan of these features shows that the causal forces, if they arose within the moon, were sufficiently strong to overcome irregularities of resistance to the accompanying movements. It thus seems incorrect to explain the formation of the walled plains by the mutual adjustments of mass anomalies when the evidence clearly shows that the irregularities of resistance were overcome in the process of formation. Explosive eruptions appear to be a more probable cause.

In asymmetrical or one-sided orogenic massifs such as the Alps, Appalachians, Ouachitas, and others, the results of rock alteration are at variance with the metamorphic consequences of this theory. Actually metamorphism increases toward the hinterland, whereas it should increase in intensity toward the basin. The inclusion of resistant pre-Cambrian rocks in the overthrusting of the Appalachians also constitutes an objection not easily surmounted. Furthermore, the southern Rocky Mountains, and other ranges, do not fit readily into any of the author's categories of orogeny.

Any unmistakable example of the elevation of rock masses against gravity during overthrust faulting and folding, on a scale large enough to be clearly without the realm of the trivial or accidental, would constitute a formidable objection to the proposed theory. Such vertical movement, however, could be demonstrated only with difficulty, if at all, since the folding manifested in compression orogeny is often more deep-seated in the later phases than in the earlier, these structures being displaced by

the development of folds of a larger order of size, as though the forces of compression were then effective at greater depths than formerly.

The reviewer is of the opinion that Alpine geology has influenced the thinking of Professor Haarmann to an excessive degree. While several investigators have advanced the view that some of the decken of the Alps slid forward under the influence of gravity, yet in other compression massifs the evidence for sliding is by no means clear.

Though the theory departs abruptly from accustomed geologic paths, the treatise has certain elements of strength that will appeal to many. For example, the author maintains that the earth is not in isostatic balance, though it may be approximately so. *It strives toward balance.* Further: movements near each other in time must not be viewed as contemporaneous. A rallying cry for those in revolt against the inexactness of some fields of geology might well be his capital phrase: "Wir dürfen Beobachtungsergebnisse nich gewohnheitsmässig abrunden!"

Less pleasing is the uncompromising tone in his criticisms of the contraction theory which he classes as intellectual superstition—not only impotent but also destructive—sterile and sterilizing. Admitting that earth contraction may take place, in his "revolt against the cult of authority" he completely discards this time-honored theory as a possible cause of tectonic movements.

In the latter part of the book is found a vague appeal for the socialization of scientific work. He writes about the desirability of substituting a new conception of social and co-operative labor for the older individualism of scientific men. In short, he attempts to say that scientific investigation is not an end in itself but the means to some greater good. Not without difficulty can students be persuaded to substitute his conception of socialism in science for the old tradition which defines scientific investigation as one of the most worth-while pursuits of man.

F. A. MELTON

"Über Druckschieferung im varistischen Gebirgskörper." By AXEL BORN. *Fortschritte der Geologie u. Palaeontologie*, Vol. VII, No. 22. 1929. Pp. 330–427; figs. 18; pls. 9.

It has been 27 years now since the appearance of van Hise's *Treatise on Metamorphism*, which, together with the work of the same geologist and his associates in the Lake Superior region and the fundamental studies by Becker and Leith, first extensively directed our thoughts to the relation between structure and metamorphism. Since then interest in this phase of geologic investigation has declined in America with a few noteworthy

exceptions, and advances have been made almost wholly through the energy and care of European geologists. Many Americans have given but little regard to the trend of thought of their colleagues across the sea, and hence attention may justifiably be directed to the results attained, even when, as in the present instance, these have already been published for a year or two—a principle already well established by the recent paper of Dr. E. B. Knopf (*Amer. Jour. Sci.*, Vol. XXI [1931], pp. 1–27).

Dr. Axel Born is noteworthy for his attempts at correlating structure and metamorphism. In the work here reviewed he concerns himself with subdivisions of the most superficial zone of regional metamorphism—that zone which in depth lies above the phyllites or epizone of Europeans. In this zone, shale and its metamorphic equivalents serve as suitable indices of subdivisions because among sediments they are the most sensitive to slight variations in compression. Six subzones are recognized, marked respectively by plastic clay shale, shale, clay-slate (lacking staly cleavage but showing some regularity of jointlike, closely spaced fractures or possessing a "slate-pencil"-like fracture), imperfectly cleaving slate ("rough cleavage") having unoriented sericite flakes as important constitutents, slate with typically smooth cleavage, and *Runzel Schieferung* (wrinkled cleavage—a type resembling closely the slip cleavage of Dale or the false cleavage of Leith and the reviewer). These rock subtypes are distinguishable not only by megascopic and microscopic criteria but also by means of water content and dye-adsorption. Through them paleogeographic inferences are drawn, chiefly of regional significance but interesting also to American geologists as illustrations of novel and ingenious modes of attack.

In a more general way, however, there are results that should concern all structural geologists. One is tempted to ask whether slip cleavage really always indicates a zone of higher metamorphism. Dr. Born himself casts some doubt upon that interpretation. Certainly the occasional appearance of slip cleavage in slate calls for a wholly different explanation from the uniform "wrinkling" in schists. In the experience of the writer, local slip cleavage in slate appears to be related to change in stress-direction or variations in initial composition—a factor which Dr. Born may perhaps be said to underrate.

A question of greater interest is the writer's flat contradiction of the parallelism between axial planes of folds and cleavage planes; figures are presented which show these two surfaces intersecting almost at right angles. Does not this relation merit a very conscientious re-examination? The care with which these studies have been carried out precludes their blunt dismissal.

Space permits only one more point. Dr. Born develops the concept that slaty cleavage is a late phase of lateral compression of a special, regionally almost uniform type, *insufficient* to produce folding. In a word, it represents the effect of the declining phase of lateral compression after folding. To some this interpretation must be wholly unacceptable when viewed regionally. If slaty cleavage were simply developed upon lateral compression insufficient to produce folding, it should be recognizable as incipient to folding; yet it is only met with in regions of closer folds, and invariably disappears completely as open folds are approached. Is it not more reasonable to assume that folding represents early response to compression; that, as the folded masses "pile up," a depth is attained which makes possible, through accumulation of static load, the development of great lateral pressures without further bedding deformation and distributes these pressures equally? This would result in recrystallization in the manner set forth by Becke and Grubenmann, and a regionally uniform slaty cleavage would ensue. The new structure or slaty cleavage is more stable and will permit the appearance of subsequent, non-cleavage structures only when the deforming force is very great; is so abruptly transmitted that further recrystallization has not the *time* to take place; and is either (1) in the same direction as hitherto, in which case fine granulation or mylonitization should result, or (2) in a different direction, in which case shear results with consequent folded cleavage, false cleavage (slip cleavage), or megascopic faulting.

CHARLES H. BEHRE, JR.

Elementary Economic Geology. By H. RIES. New York: John Wiley & Sons, Inc. 1930. Pp. vii+360; figs. 136; pls. 29. $6.00.

This excellent book is essentially a condensation of the latest edition of Dr. Ries's *Economic Geology* to meet the requirements of a course in economic geology extending through only one term. Its 360 pages are divided into a first part dealing with non-metallics and a second part dealing with ore deposits. The numerous well-selected footnote references serve to direct the students who are interested to the sources of more detailed information. The illustrations are well selected, and the simple maps showing the location of districts of economic importance are an especially valuable feature.

Some idea of the method of treatment may be gained from the chapter dealing with gold and silver. After listing the ore minerals, the principal genetic classes of gold and silver deposits and the effects of weathering and enrichment on the primary deposits are discussed. There follow brief

descriptions of the different genetic types, including contact metamorphic deposits; veins of deep, intermediate, and shallow origin; and placers. The distribution of gold and silver deposits is next considered. Mining and extraction methods are briefly described, salient statistics of production are given, and the uses of these metals are discussed.

The amount of space devoted to coal is 32 pages; to petroleum and natural gas, 26 pages; iron and copper are allotted 18 pages each; and other resources receive smaller allotments of space. The book closes with a 2-page selected list of reference works of a general character. The subject matter of the book is well organized and expresses very well the modern viewpoint on the genesis of the various mineral deposits described. The reviewer's only criticism of the book is that it is perhaps too encyclopedic and too comprehensive for an elementary text and that it would have been strengthened by the wilful omission of many of the minor mineral resources, a fuller discussion of the major ones, and a fuller consideration of principles.

E. S. B.

Stratigraphy and Paleontology of the Paleocene of Northeastern Park County, Wyoming. By G. L. JEPSEN. *Proceedings of the American Philosophical Society*, Vol. LXIX, No. 7. 1930. Pp. 463–528; pls. 10.

The Puerco and Torrejon beds of New Mexico have been famed since the days of Cope for the presence of an abundance of primitive mammals of small size and archaic structure. The position of these "Paleocene" faunas in the vertebrate sequence, however, has been a debatable one.

In Wyoming and adjacent regions there is a well-known series of Mesozoic faunas ending with the Lance (which for the vertebrate paleontologist, if not for the U.S. Geological Survey, marks the end of the Cretaceous); higher up there is a good Tertiary sequence beginning with the true lower Eocene. Between lies a series of deposits, often of great thickness and with vague and variable boundaries, usually lumped as the "Fort Union." It has been believed by most paleontologists that the Puerco and Torrejon of the New Mexico Paleocene were to be correlated with these beds, but no positive statement could be made, for vertebrate remains are exceedingly rare in the Fort Union. There are no dinosaurs in the New Mexican beds, suggesting that these deposits were of later date than the Lance. But it was equally possible that they merely represented a different facies of the same fauna, one in which the dinosaurs had become lo-

cally extinct. Again, certain genera are common to these Paleocene faunas and that of the true lower Eocene, and there was but little geologic evidence to show that they were of much earlier date.

Jepsen's work has resulted in the solution of this problem. He has found and described good Puerco and Torrejon faunas in the Bighorn Basin of Wyoming. The mammalian remains are interesting in themselves. But still more interesting is the fact that they are found in the Fort Union, quite definitely above the Lance, and equally definitely below the lower Eocene ("Wasatch").

That in the Cretaceous-Tertiary sequence of the Bighorn region the only break of note is between the Lance and Puerco, and that this disconformity marks the greatest faunal change are facts of interest in connection with the problem of the Mesozoic-Cenozoic boundary. But, as Jepsen remarks, in such a controversy "a judicious selection of data can 'prove' two opposed conclusions with equal facility."

A. S. R.

Studies of Fossil Mammals of South America. A Partial Skeleton of Homalodontotherium from the Santa Cruz Beds of Patagonia. By WILLIAM BERRYMAN SCOTT. *New Carnivorous Marsupials from the Deseado Formation of Patagonia.* By WILLIAM J. SINCLAIR. Field Museum of Natural History. "Geology, Memoirs," Vol. I, No. 1. 1930. Pp. 39, pls. 8.

Ameghino and other early workers on the paleontology of Patagonia revealed to us a new world of mammalian life; but at the same time, as a result of hasty and incomplete descriptions and ill-founded generalizations, they left for us a taxonomic tangle and a series of very inadequate morphological pictures of the forms described. The Princeton expedition three decades ago did much toward clearing up the morphology of the Santa Cruz mammals, and the later Amherst expedition resulted in a valuable contribution to our knowledge of the Deseado forms. A great deal, however, remains to be done. The recent Field Museum expeditions, under Curator Riggs, have resulted in the collection of an extremely valuable series of speciments. It is to be hoped that the present publication is but the first of a series which should go far toward solving the many remaining problems in the taxonomy, morphology, and phylogeny of the Patagonian fossil mammals.

A. S. R.

ATTENTION OF MINERAL COLLECTORS

The Mineralogical Society of America is attempting to compile a list of the more important mineral collections, both public and private, in the United States and Canada, the intention being to publish this information in the form of a regional directory in the *American Mineralogist.*

While the securing of the necessary data relating to the larger public collections housed in museums and institutions presents little difficulty, the task of collecting information upon the smaller private collections, either general or specialized, that exist on this continent is more formidable. It is believed that there probably exists, in various smaller centers and mining districts, a wealth of interesting and valuable mineralogical material, some of it possibly collected years ago and from localities no longer accessible, which is virtually unknown to the scientific world. It is of decided value and interest to the owners of such material that the existence of their collections should be recorded, both from the standpoint of the possible scientific value of the material and with a view of enabling the owners to establish contacts with mineralogists who may find themselves in their districts and desire to examine the collections.

Accordingly, the Mineralogical Society of America wishes to ask all readers of this announcement who may be mineral collectors, and who own either general or specialized collections, to kindly send their names and addresses, together with a brief note on the nature of their material, to the address given below. If the collection is specially rich in minerals of a particular mine, locality, or district, this should be mentioned, as should also the inclusion of any specialized types, such as gems, meteorites, or other notable rarities.

In the case of public collections, the name of the institution, together with the name and address of the custodian or director, is desired.

In addition, the Society would welcome information, with notes as above, regarding other collections known to the correspondents, and which they consider should be included in the directory.

Details relating to collections consisting wholly of the minerals and ores of an individual mine, and on permanent exhibit at the mine office, will also be welcomed from mine owners, managers, superintendents, and engineers. The names and addresses of small local dealers specializing in the minerals of particular localities will also be of interest.

Since the success of the survey being made will very largely depend upon the co-operation of those individuals in possession of this information, an earnest appeal is made for as full, complete, and prompt replies as possible. Address all correspondence to *Samuel G. Gordon, Philadelphia Academy of Natural Sciences, Logan Square, Philadelphia, Pennsylvania.*